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Investigation of Alternative Locally Available Feedstock Sources for
Biodiesel Production in Ethiopia:
viz. R.communis, B. carinata, J.curtas & E. guineensis

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Dedication: - To my sons, Latera Mesfin
&
Ifera Mesfin
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ACRONYMS

AR  Analytical reagent
ASABE American Society of Agricultural and Biological Engineers
ASTM American Society for Testing and Materials
AWARC Awassa Agricultural Research Center
BD  Biodiesel
ABSTRACT
The world is facing severe energy crisis attributed to global oil reserve depletion, increasing consumption rate, incessant oil price hike and above all environmental concerns (air pollution and emission of Greenhouse Gases) dictate that the world community must hunt for alternative and sustainable energy sources. One of the mitigation efforts considered in response to the crisis is finding substitute for petroleum oil. Biofuels are becoming the most reliable energy sources, among which, biodiesel attracted attention to substitute for the ever-increasing petrodiesel demand and consumptions for every activity of human beings. This research project assessed the potential of biodiesel production from oil seeds in Ethiopia and the qualities were compared to identify the most suitable species. Samples of oil seeds were collected from different locations. Suitable areas were delineated using ArcGIS software and the spatial analyst tool. Soxhlet extraction method was used to extract oils from each species, using solvent, hexane. The biodiesel was synthesized by transesterification process and characterized by determining density, kinematic viscosity, iodine value, saponification number, peroxide value, cetan number, heating value, cloud point, flash point, acid number and distillation test. GC analysis was conducted to determine the fatty acid compositions. The oil content results from the five collections of R. communis ranged from 36.45 to 45.76 %w. B. carinata rendered oil content of 47.62 %w and J. curcas, investigated at three different conditions resulted oil contents ranging from 29.55 to 41.04 %w. The gross heat contents of the biodiesels from B. carinata, J. curcas, R. communis and E. guineensis were found to be 39.31, 38.71, 36.86 and 38.95 MJ/kg respectively. J. curcas conforms with all the standard specifications of ASTM D 6751 and EN 14214, except for its flash point result of 120 °C i.e., less than the EN 14214 specification. R. communis fails to meet both the standards having density (0.9269 g/mL), kinematic viscosity (10.94 mm/s) and flashpoint (95 °C) and that of EN standard due to its acid No. (0.566 mgKOH/g). B. carinata meets both standards, except in acid number result of 0.885
mgKOH/g, which exceeded both limitations, and kinematec viscosity result of 5.09 mm
2
/s
exceeding the range set by EN 14214. E. guineensis fails to meet both the standards in density
(0.9121 g/mL), kinematic viscosity (13.91 mm
2
/s) and acid number (1.802 mgKOH/g). It can be
concluded that, amongst the oil plants investigated, J. curcas surpassed in every aspect, that
rendered it the most suitable and potential candidate as a substitute for diesel, seconding B.
carinata, while R. communis and E. guineensis can be used up to 20% blends with the other two.
Moreover, the physicochemical characteristics were improved by blending the biodiesels from
different oils, and promisingly agreed with the standard specifications.

Key words: Transesterification, Biodiesel, alternative feedstock, area suitability, physicochemical properties,
blends.

I. INTRODUCTION

1.1 Background
The majority of the world’s energy needs are supplied through petrochemical sources (oil,
coal, and gas) covering more than 80% of the world’s primary energy consumption (IPCC,
2001), all of which are finite and at current usage rates will be depleted in this century
(Khan, 2002; Orhan et al., 2004).

Moreover, the persistent hike in global prices of crude oil (from 13.08 in 1978 to over 102
USD/bbl in 2008) (U.S. EIA, 2008) is becoming the major issue in every country. The
situation was exacerbated, owing to ever increasing demand; in the face of continued
decline in quantity of crude petroleum, dwindling production rate, the instabilities in the
centers of petroleum production (Darkwah et al., 2007) and the processing costs such as;

desulphurization in order to meet stringent emission norms etc. (Subramanian et al., 2005)
(Figure 1). This, inevitably, reflected an adverse impact on the local economy of many
countries, especially the oil importing countries, by posing a severe burden on their foreign
exchange (Bol et al., 2004).

Figure 1: World oil price fluctuations analysis

Source: (Adopted from Williams, 2007)
In view of this analysis, the spread of fossil-energy-intensive approach to developing countries and economies in transition, with large population, may be constrained by numerous factors in addition to limited resource availability and concerns about environment and human health, which all together rendered the developing countries energy deficient (Francis et al., 2005). Moreover, lack of modern energy services in rural areas hampers efforts to alleviate poverty and improve living standards while leading to health and environmental problems (AFREPREN/FWD, 2004).

Therefore, the aforementioned obsessive issues were considered to be the important trigger for many initiatives to search for the alternative source of energy, which can supplement or replace fossil fuels (Azam et al., 2005) thereby, the need for such alternatives has been driven world wide by economic, environmental, political and social factors (Batidzirai, 2007).

Amongst the identified alternative renewable energy sources, biofuels and in particular energy crops received attention as a promising and sustainable energy sources, of which, Biodiesel has arisen as a potential candidate for a petrodiesel substitute. Its production increased at a faster rate across the world, at an average rate of 32% per year, between 2000 and 2005 (Gubler, 2006), due to the similarities it has with petroleum-based diesel and can be used in conventional diesel engines without significant modifications (EC, 1997; Venendaal et al., 1997).

It is also attractive because biodiesel can be produced easily from common feedstocks (lipid sources such as; vegetable oils, animal fats and recyclable cooking oils), and furthermore can be blended with diesel fuel at any proportion in the existing plants without major changes in infrastructure and many other potential benefits (Sharp, 1998; Agarwal and Das, 2001; Khan, 2002; Kalligeros et al., 2003).

In addition to local energy production and poverty alleviation endeavors, biodiesel industries will also benefit the country through the implementation of clean development mechanism (CDM), defined in Article 12, that provides a mechanism for developed countries to implement projects which reduce emissions in non-Annex I Parties, in return for certified emission reductions (CERs) (Rothkopf, 2007).

1.2 Rationale of the study
Ethiopia is one of the developing countries, with large population residing in rural areas, (85% out of the 77 million) (CSA, 2007) based on out-dated agricultural practices and under pressure of intense land utilization (Appendix 6) and entirely dependent on raw biomass energy utilizations for basic needs, like cooking, and lighting. This situation has resulted severe deterioration of forests, changing agricultural lands into wastelands, low productivity and hence; the people terribly entangled with the vicious circle of poverty, hunger and malnutrition.

Alternative commercial energy sources are limited mainly to urban areas; due to high prices, shortages, uncertain supply, and difficult distribution of these energy sources especially in remote areas. Moreover, the recent steadily increasing retail prices of fuels is
also alarming, that has got direct impacts on the livelihood of the citizens. Increment on Addis Ababa retail price of fuels (in the past three years) was 90.7, 74.7 and 60.5 % for kerosene, gasoline and diesel respectively (EPE, 2007). Moreover, despite the price increase, the demand for liquid fuel is ever increasing, in line with the increasing number of transportation fleets, construction and agricultural machineries as well as grain mills & water pumps for irrigation in the rural areas (Appendix 4).

Hence, assessing sustainable and renewable energy alternatives is indispensable at present, due not only to combat the fuel supply uncertainty and price fluctuations, but also becoming global concern and each country’s responsibility to seek for environmentally benign energy sources that are proponent to the global endeavors to reduce Greenhouse Gases and air pollutions. In this respect, Ethiopia, the country deprived of conventional fossil fuels in its territory, has multiple burdens of uplifting the per capita energy access; that has been the least on the world (277.9 Kgoe, (IEA, 2006)); stabilizing the price fluctuations and continuous price rise, poverty alleviation, as well as attaining environmentally sound and renewable energy sources for the country.

A number of countries have successfully applied the use of biodiesel made from plant seed oils or animal fats, purely or by blending with petroleum diesel, and developed appropriate technologies to exploit the resources specific to their geography, which however, limited most to specific oilseed crops like soy bean (in USA) and canola (in EU) due to their agroclimatic conditions. Such oil crops may not be convenient in Ethiopian situation to cultivate for biodiesel production, as they require large fertile land besides competing food crops.

Indeed, Ethiopia has ample opportunities and potential for the production of varieties of both edible and non-edible oilseeds and oil fruits, due to the country’s favorable agroecology (climate and soil). Most of such plants are not yet exploited or even not identified, hence, abandoned and left in vain as weeds. In addition, the country has enormous potential for ethanol production as a byproduct from sugar factories, that could be used as a major input for biodiesel production (Appendix 3).

However, the oils from different plant species have varying fatty acids profiles that influence the biodiesel fuel properties, as cetane number, heat of combustion, cold flow properties, oxidative stability and viscosity. Therefore, it is important to possess data on how the various fatty acid profiles of the different sources can influence biodiesel fuel properties.

Accordingly, developing the methods to identify suitable plant oils, for biodiesel production, is indispensable. However, it requires scientific evidence to make the production to reality in this country, from such novel resources, and evaluating economically feasible varieties in view of yield per hectare, usable energy per unit weight as well as oils’ characteristics affecting their suitability for use as fuel; the data of which is totally lacking in Ethiopia at present. On the other hand, many investors are importing, recently, almost the same type of oilseed crop species, meant for biodiesel production, from elsewhere abroad (Appendix 5); and such situations in the long run, may jeopardize the indigenous species diversity in the country.

Therefore, to identify the most feasible and reliable oil crops for biodiesel from indigenous or local oil plant species, area suitability assessment and the key fuel properties tests of oils are essential for finding solution to the aforementioned problems.
The ultimate goal of the present study is therefore, to identify alternative feedstocks for biodiesel production in Ethiopia from various inedible oil bearing plant species adapted to the country’s geography. Based on the agroclimatic zones of the country, different methodologies were used to assess the oilseed plants. The agricultural requirements were investigated using information available at agricultural research centers in the country; such as Awassa, Kulumsa, Essential Oils and Holetta research centers. Moreover, review of literatures, field investigations and interviews to the local communities were conducted using questionnaires. The oil seeds considered and compared were Castor (Ricinus communis L.), Physic nut (Jatropha curcas L.), Ethiopian Mustard (Brassica carinata Braun) and Oil Palm (Elaeis guineensis Jacq.).

Oil extraction, biodiesel synthesis and fuel’s characteristics tests were conducted at Addis Ababa University department of chemistry, Essential oils Research center, Geological Survey of Ethiopia and Ethiopian Petroleum Enterprise laboratories. The physico-chemical parameters considered in the present study include; density, kinematic viscosity, iodine value, saponification number, peroxide value, cetan number, heating value, cloud point, flash point, acid number and distillation test. Finally, the results were compared against the standard specifications of ASTM and EN.

5
1.3 Objectives

1.3.1 General Objective
Identification of appropriate alternative locally available feedstock resource bases, for innovative approach to biodiesel production in Ethiopia, from among the inedible oil bearing plant species adapted to the country’s geography.

1.3.2 Specific Objectives
i. To assess and collect seeds of the various inedible oil bearing plant species in Ethiopia, namely, Ricinus communis L., Jatropha curcas L., Brassica carinata Braun and Elaeis guineensis Jacq..
ii. To investigate their growth habit, environmental requirements and yield potentials,
iii. To determine the crude oil content and biodiesel weight percent of extracts from each studied oilseed resource base,
iv. To determine the fuel physicochemical properties such as, acid value, saponification number, peroxide value, density, kinematic viscosity, iodine value, flash point, boiling point (distillation test), cetan number, heating value and cloud point for each,
v. To determine appropriate biodiesel fuel properties and optimization by blending of fatty acid esters (FAEs) from different oils with various fatty acid compositions for inferior feedstock resource bases.
vi. To evaluate the specific economic and environmental advantages.

1.4 Significance and application of the result

The concept of substituting biodiesel produced from plants’ oils native to the country, particularly inedible oils, is novel to the country and indispensable to mitigate the overwhelming energy problems in a sustainable way. Generally, the results of the study will be used as base-line information for further studies, show the direction to prefer the potential and productive species particularly for small scale production of plant oils as feedstock sources for biodiesel production, in Ethiopia.
II. REVIEW OF LITERATURE

2.1 Diesel combustion and fuel property requirements
Diesel combustion is the process that occurs when a hydrocarbon fuel, chosen for its ability to auto-ignite, is injected into a volume of air that has been compressed to a high temperature and pressure (around thirty atmospheres pressure) (Quick, 1989). Diesel engines do not use carburetors and rely on spontaneous combustion for fuel ignition, so the fuel must be atomized upon injection into a very fine mist to ensure a complete burn (Van Gerpen et al., 2004). The four stroke engine is the most common engine type nowadays in which, the four strokes of the cycle are; intake, compression, power, and exhaust (http://www.keveney.com/Engines.htm 2007-09-15). However, although the fuel injection system is designed for petroleum diesel, similar results can be found if the viscosity of the plant oils and animal fats is lowered to nearly that of diesel fuel (http://www.journeytoforever.org/biodiesel_svo.html2007-08-11).

2.2 Raw vegetable oils and animal fats as a substitute for diesel oil and their effect on engine performance
Oils and fats are composed of molecules called triglycerides, which chemically are glycerol molecules with each of their three hydroxyl group esterified with a long clown fatty acid (8-22 carbon atoms) (Figure 2). This resulted high viscosity of oils and are chemically quite distinct from the oils used in petroleum industry, which are generally hydrocarbons (Gunstone, 1958; Gurr et al., 2002; Kinast, 2003).

Figure 2: Fatty Molecule (Triglyceride)
Source: (Gunstone, 1958)

Before 1920s the compression-ignition engine, patented by Rudolf Diesel, used large injectors to prevent clogging by the viscous, heavy fuels, which were unrefined petroleum and vegetable oils, but soon replaced by smaller diesel engines, which required lower viscosity fuels. Raw plant oils may not properly function in such smaller engines (Knothe et al., 1996; Gurr et al., 2002; Bradley, 2006).

H          O
   | II
H-C-O-C-CH
  2
-CH
  2
-CH
  2
-CH
  2
-CH
  2
-CH
  2
-CH
\[\text{Stearic} \quad \text{O} \]
\[\text{H-C-O-C-CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{3} \quad \text{Oleic} \quad \text{O} \]
\[\text{H-C-O-C-CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad \text{-CH=CH-CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
\[\text{2} \quad -\text{CH} \]
Nowadays, dozens of experiments have revealed that, direct use of fats and oils or their blend with petrodiesel in turbocharged direct injection engines, such as trucks, could cause certain problems (Friedrich, 2004),

due to high viscosity (that cause problems with flow of oils from the tank to the engine, blockages in filters and subsequent engine power losses) (Quick, 1989). In addition, cocking and gumming which leads to sticking of piston rings due to multi-bonded compounds undergoing pyrolysis, and polyunsaturated fatty acids also undergo oxidation in storage causing gum formation and at high temperatures complex oxidative and thermal polymerization can occur (Ma, 1999; Shaine, 2001; Khan, 2002).

2.3 Characteristics of petroleum-derived Diesel fuel
Petroleum fuels are blends of lots of different chemical species that are refined from crude petroleum and may be categorized as either a distillate fuel or a residual fuel depending on the method of production. Diesel fuels (no. 2D) predominantly contain a mixture of C

through C

10

hydrocarbons, which include approximately 64% aliphatic hydrocarbons,
saturated hydrocarbons (primarily paraffins including n, iso, and cycloparaffins), 1-2% olefinic hydrocarbons, and 35% aromatic hydrocarbons (including naphthalenes and alkylbenzenes). Cetane (C
16
H
34
) is a typical of diesel fuel (Figure 3). Fuel oil no. 1 (straight-run kerosene) is a light distillate which consists primarily of hydrocarbons in the C
9
-C
16

Figure 3: Cetane (n-hexadecane) (C
16
H
34
), typical of diesel fuel
Source: (Fuel Chemistry, 1998)

Petrodiesel is further classified as No. 1, No. 2, and No. 4 diesel fuel (DF) by the standard ASTM D975. No. 1 (DF1) is obtained from the 170â€“270°C boiling range (as are kerosene and jet fuel) and is applicable to high-speed engines whose operation involves frequent and relatively wide variations in engine load and speed. No. 2 (DF2) is in the 180â€“340°C boiling range. This grade is suitable for use in high-speed engines under relatively high loads and uniform speeds. No. 4 DF (DF4) comprises more viscous distillates (http://www.mechanicalengineering.com/2007-04-01). Lube Oils are from 340 to 540°C, residual oil 340 to 650°C and asphalt above 540 °C www.me.iastate.edu/biodiesel/Pages/bio16.html  [6.9.2003].

8
2.4 Modern processes of Biodiesel production
2.4.1 The basic concept
Biodiesel is defined as the mono-alkyl esters of long chain fatty acids (derived from vegetable oils or animal fats). It is the product of the reaction of a straight chain alcohol, such as methanol or ethanol (in the presence of catalyst-NaOH, KOH or Sodium methoxide) with a fat or oil (triglyceride) to form the mixture of fatty esters of long chain fatty acids (Biodiesel) and glycerol (glycerin) (Sridharan and Mathai, 1974; Kinast, 2003; Van Gerpen et al., 2004). Biodiesel represents a suitable renewable substitute for petroleum based diesel (Khan, 2002) and is accepted as an alternative diesel fuel in a steadily growing number of countries around the world (Knothe, 2005). Fatty acid methyl esters or ethyl esters (FAME/EE), from vegetable oils, have shown promise as Biodiesel, as the result of improved viscosity, volatility and combustion behavior relative to raw triglycerides, while maintaining their cetane number (around 50) (Alcantara et al., 2000).

2.4.2 Technological platforms
Vegetable oils are produced from numerous oil seed crops with varying fatty acid composition. While all vegetable oils have high-energy content, most require some processing to assure safe fuel use in internal combustion engines (Kalligeros et al., 2003).
Various methods were used to produce fuels from vegetable oils or fats including; direct use of vegetable oils & fats and/or blending at different proportions with diesel, microemulsions with simple alcohols, thermal cracking (pyrolysis) to alkanes, alkenes, alkadienes etc., batch wise transesterification (alcoholysis) (Figure 4) and the continuous base-catalyzed process (Appendix 13) (Tapasvi et al., 2004; Weiksner et al., 2006).

The continuous base-catalyzed process is the most widely used biodiesel process in the European Union and US which is divided into four main sections, namely; crude oil degumming, refining and drying; transesterification reaction, ester washing and methanol recovery and glycerol refining. But, in the case of batch wise process, transesterification is most commonly used method (Ma, and Hanna, 1999; Srivastava and Prasad, 2000; Khan, 2002).

Rice et al (1999) and Van Gerpen et al (2004) reported that a number of approaches are available for ensuring the transesterification reaction occurs quickly enough to be practical. The following groups classify these options:

- **Base catalyzed reaction-** using NaOH, KOH, NaMeO
- **Acid catalyzed reaction-** using H2SO4, H3PO4, HCl, BF3
- **Lipase Enzymes catalyzed reaction**
- **Non-catalyst options such as supercritical processes, and co-solvent systems.**

Figure 4: Biodiesel Production Process

Source: (Weiksner et al., 2006)
2.4.3 Base Catalyzed Reaction

2.4.3.1 Transesterification
Transesterification (also called alcoholyis) 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), (Figure 5), in which lipids react with an alcohol to form monoakyl 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, time, the contents of free fatty acid (FFAs) and water in oils (Demirbas, 2003).

Transesterification is conducted to produce biodiesel with the objective to reduce the viscosity of the parent vegetable oil or animal fat, since it is an order of magnitude greater than that of the corresponding methyl esters (Biodiesel). Peterson et al., 1998 reported that the viscosity of canola oil was 37 mm²/s and reduced to 4.7 mm²/s after transesterification (Peterson et al., 1998; Van Gerpen et al., 2004).

Source: Van Gerpen et al., 2004

Potassium hydroxide has added advantage since, at the end of the reaction, the waste mixture can be neutralized with phosphoric acid resulting in potassium phosphate, which can be used as fertilizer (Isigigur et al., 1994). Suitable feedstocks for a base-catalyzed process transesterification require FFA < 1 % (acid value of oil should be below 2mg KOH/g) and preferably < 0.05 %, according to ASTM and EN standards (Van Gerpen et al., 2004; Ghadge and Raheman, 2005).
Transesterification involves three stepwise reactions with intermediate formation of diglycerides (DG) and monoglycerides (MG) resulting in the production of 3 mol of methyl esters (ME) and 1 mol of glycerol (GL) (Figure 6) (Freedman et al., 1986; Noureddini and Zhn, 1997).

The molar ratio (6:1) of either ethanol or methanol to crude oil is required during biodiesel production, by employing the transesterification method, (rather than the 3:1 ratio required by the reaction stoichiometry), which is 100% molar excess alcohol. As the reaction is reversible (Figure 6) excess alcohol is used to force the equilibrium to the product side (Peterson et al., 1998; Ma, 1999; Khan, 2002).

Ethanol as an additive or a reactant is often preferred in place of other simple alcohols, such as methanol because it is less toxic and it is easily produced from renewable sources such as biomass or grains (Foglia et al., 2000). However, some countries most commonly use methanol for producing biodiesel since it is the least expensive alcohol in their respective countries, and moreover, the difference in boiling point between the two alcohols makes methanol considerably easier to recover than the ethanol (Van Gerpen et al., 2004).

2.4.3.2 Acid Catalyzed Reaction
Although the acid-catalyzed reaction requires a longer reaction time and a higher temperature than the alkali-catalyzed reaction, acid catalysis is more efficient when the amount of free fatty acids in the oil exceeds 1%. Moreover, an economic analysis study has shown that the acid-catalyzed procedure is more economical than the alkali-catalyzed process by avoiding soap formation (Freedman et al., 1984; Liu, 1994).

2.4.4 Catalyst requirements for continuous process
Suitable heterogeneous catalyst that fulfils the high reaction rate requirements as well as features such as; insolubility in the reaction mixture, long working life, suitable particle size, high temperature resistance and large surface area are basic requirements for continuous process (Khan, 2002). In the cases when the amount of free fatty acids in the oil exceed 1%, homogenous acid catalyzed reaction is more efficient (than direct alkali catalyzed), since it eliminates the problem with saponification when esterification occurs. However acid catalysts have impact on equipment and at elevated temperatures severely affect any metallic components (Khan, 2002 Van Gerpen et al., 2004). Darnoko and Cheryan (2000) reported test result on palm oil that, the rate of transesterification in a batch reactor increased with temperature up to 60°C. However, higher temperature does not reduce the time to reach maximal conversion. The optimal catalyst concentration is 1% KOH, expressed as a weight percentage of the oil (Darnoko and Cheryan, 2000).
2.4.5 Side-reactions affecting the yields of fatty esters from transesterified oils and fats

2.4.5.1 Hydrolysis
Fats can be hydrolyzed by water or alkali (Khan, 2002), with production of long chain fatty acids and glycerol (Figure 7). The naturally occurring fatty acids are chiefly straight-chain compounds containing an even number of carbon atoms and conveniently divided into saturated, unsaturated and branched chain acids (Gunstone, 1958).

![Figure 7: Hydrolysis of Fats](source: Gunstone, 1958)

2.4.5.2 Saponification
Some amount of soap is produced during biodiesel production, using an alkali catalyst, and there will be more soap with recycled restaurant waste oil and animal fats (due to large amounts of FFA >1% w/w) and less with refined vegetable oils (Freedman et al., 1984; Demirbas, 2003). The production of soap sometimes called alkaline hydrolyses, converts triacylglycerols to glycerol and a mixture of salts of long-chain carboxylic acids (Figure 8). However, the production of fatty acids is an intermediate step when triglycerides are directly used for saponification (Khan, 2002; Van Gerpen et al., 2004).

![Figure 8: Saponification from free fatty acids](source: Van Gerpen et al., 2004)

13 Therefore, fats and oils with a free fatty acid content greater than about 1 % must be pretreated to either remove the FFA or convert the FFA to esters before beginning the base catalyzed reaction (Canakci and Van Jerpen, 1999). Otherwise, the base catalyst will react with the free fatty acids to form soap and water. The soap formation reaction is very fast and goes to completion before any esterification begins (Demirbas, 2003; Freedom et al., 1984). After the transesterification reaction is complete, the leftover catalyst and soap tend to concentrate in the glycerol phase. However, some soap and a small amount of catalyst may be left in the biodiesel phase. During process development, it can be useful to know the amount of soap formed, where the catalyst resides, and how effective the washing process is in removing these two compounds (Van Gerpen et al., 2004; Ghadge and Raheman, 2005).
2.4.5.3 Esterification
The acid catalyzed esterification (a condensation reaction) occurs by the reaction of carboxylic acid (fatty acids) and alcohols in the presence of strong acids (Figure 9). Acid catalyzed processes are used for direct esterification of free fatty acids (FFAs) with a high FFA feedstock, or to make esters from soap stock (Zheng et al., 2006).

Figure 9: Esterification reaction
Source: (Zheng et al., 2006)

2.4.6 Factors determining production cost of biodiesel

2.4.6.1 The basics of Biodiesel generation
The basic chemistry of the biodiesel production reaction requires 3 molecules of methanol or ethanol for every molecule of triglyceride, which corresponds to about 10% the weight of alcohol per mass of oil processed. The catalyst ratio is roughly 10% of the alcohol mass (Coltrain, 2002; Van Gerpen et al., 2004). Kinast (2003) indicated the input/output components, for a given mass of pure oil, in the reaction to produce biodiesel (Table 1). The cost of production hence is determined by how efficiently these components used. Production method i.e.; high consumption of catalyst and low yields of ethyl esters in conventional processing (the batch-wise reaction) disadvantages it because of high capital cost, labor intensity and difficult process and product quality (Khan, 2002).

Table 1: Essential input- output components of biodiesel production

<table>
<thead>
<tr>
<th>Input streams:</th>
<th>Unit For 100 kg oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary alcohol (Ethanol)</td>
<td>kg 10.7</td>
</tr>
<tr>
<td>Catalyst (KOH)</td>
<td>kg 0.1</td>
</tr>
<tr>
<td>Neutralizer (Phosphoric acid)</td>
<td>kg 0.8</td>
</tr>
<tr>
<td>Water</td>
<td>kg 1.7</td>
</tr>
<tr>
<td>Electricity</td>
<td>kWh 2</td>
</tr>
</tbody>
</table>

Output streams:
- Biodiesel | kg 100 |
- Glycerine | kg 12.5 |
- Fertilizer | kg 2.3 |

Source: Adopted from (Kinast, 2003)

2.4.6.2 Effects of qualities of feedstock resource bases on the cost of biodiesel production
The raw materials being exploited commercially by the biodiesel producing countries constitute the edible fatty oils derived from rapeseed, soybean, palm, sunflower, coconut, linseed, etc. (Korbitz, 1999). However, the high value of such oils as a food product makes production of a cost-effective fuel very challenging (Canakci and Van Gerpen, 2001). Therefore, the relative cost of biodiesel is higher due to its being produced mostly from expensive high quality virgin oil and/or refined oils and fats. Use of low-cost feedstock such as waste frying oils and non-edible oils in an acid catalyzed process should help make biodiesel competitive in price with petroleum diesel (Zhang...
et al., 2003).

Among the barriers for the use of resource base is the limit of the iodine number (max. 120) which is fixed in the pre-standard for vegetable oil methyl ester in different countries. This would mean, that, e.g., normal sunflower oil with an iodine number of about 130 could not be used for the biodiesel production (Prankl and Wargetter, 1996) since, a high content of unsaturated fatty acids in the esters (which is expressed by a high Iodine number) increases the danger of polymerization in the engine oil (Korus and Mousetis, 1984).

2.4.7 Biodiesel blending and optimization

Biodiesel can be used as B100 (neat). However neat biodiesel; because of having a narrow range of boiling points, slightly higher viscosity and higher carbon deposition than petroleum diesels often requires blending with petroleum diesel (Sarma et al., 2005).

Hence, blends with a petroleum diesel, at different proportions as B5, B20, B80 (a blend of 5%, 20% and 80% biodiesel with 95%, 80% and 20% petrodiesel by volume respectively) and so on are used. Cloud point and pour point are therefore adjusted by blending. Blending up to 5% is also useful for lubricating purpose (Schumacher et al., 1991; Van Gerpen et al., 2004).

2.4.8 Quality of feedstock resources base and impacts on biodiesel characteristics

2.4.8.1 The impact of Agro-ecology on the feedstock resource bases

Due to plants’ agroclimatic requirements the feedstock resources bases of biodiesel vary with location and each source comprise various fatty acid profiles of characteristic value. The properties of the various individual fatty esters and the alcohol moieties, in turn determine the overall fuel properties of the biodiesel fuel (Knothe, 2005).

In Europe, rapeseed and sunflower oil are the major sources of biodiesel, while in US animal fat and soybean oil are used (Gubler, 2006). Soybean is a major U.S. crop and subsidized by the government that make the fuel economically attractive to consumers who need or want to use a nonpetroleum-based fuel. Biodiesel from soybeans is sometimes called soy-diesel, methyl soyate, or soy methyl esters (SME) while that made from rapeseed oil is known as rapeseed methyl esters (RME) or rapeseed ethyl esters (REE) (Van Gerpen et al., 2004).

Southeast Asia (Thailand) uses Palm oil and jatropha, China uses recycled oils and jatropha, India uses Jatropha, Australia uses animal fats and Ireland uses waste frying oil and animal fats as feedstock for Biodiesel production (Mate, 2006; Gubler, 2006).

In Brazil feedstocks can be a variety of sunflower seeds, soybeans, or castor. Castor is the best option to make biodiesel, because it is easier to plant and costs less than soybean, sunflower or other seeds (Gubler, 2006; Biodiesel around the World, 2007).

The substitution of conventional diesel fuels with rapeseed oil methyl esters comprises already a commercial activity in many countries of Central Europe (ABI, 1997). However the use of biodiesel has not expanded into other Southern European countries, due to the lack of rapeseed cultivation. Some other types of vegetable oils, such as sunflower oil, corn oil and olive oil, that are abundant in many Mediterranean areas, along with some wastes, such as used frying oils, appear to be attractive candidates for biodiesel production.
2.4.9 Physicochemical properties of oils and their impact on the production and properties of biodiesel

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).

Generally, the major fuel properties as, cetane number (with relation to combustion and exhaust missions), heat of combustion, melting point, and viscosity of neat fatty compounds increase with increasing chain length and decrease with increasing unsaturation (iodine value), (Error! Reference source not found.); (Knothe, 2005; Van Gerpen et al., 2004). Hence, it appears reasonable to enrich certain fatty esters with desirable properties in the fuel, possibly oleic acid, in order to improve the properties of the whole fuel (Knothe, 2005).

2.4.9.1 Cetane number

Cetane Number (CN) or aniline point is a relative measure (the scale) of the interval between the beginning of injection and auto-ignition of the fuel (conceptually similar to the octane scale used for gasoline). The cetane number is the primary specification measurement used to match fuels and engines (Van Gerpen et al., 2004). The higher the CN, 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) (Azam et al., 2005). Fuels with low CNs will result in difficult starting, noise and exhaust smoke. In general, diesel engines will operate better on fuels with cetane numbers >47 (ASTM D 613). Cetane Index â€“ (ASTM D 976 or D 4737) is a calculated quantity that is intended to approximate the cetane number (Van Gerpen et al., 2004).

2.4.9.2 Energy Content

It is the amount of heat released during the combustion of certain fuel and measured in units of energy per amount of material (Btu/lb, MJ/kg etc.) or a variety of other combinations of units. It is also defined as the enthalpy of combustion (or the heat of combustion). Heating value is usually determined by use of a bomb calorimeter (Heating value, 2007). The heating value depends on the composition of the fuel. Since all the oils have very nearly the same carbon, hydrogen and oxygen contents the gross and net heating values of each fuel per unit mass will be close to each other (Kinast, 2003).

Biodiesel has a lower energy content (lower heating value) than conventional diesel fuel (Table 2). On a weight basis, the energy level is reported to be 12.5% less. The energy density per-volume is directly proportional to the fuel density, and since Biodiesel is more dense than the diesel fuel (0.87-0.88 g/cc for Biodiesel compared with 0.84-0.85 g/cc for No. 2 diesel fuel), the energy content is only 8% less on a per volume basis. Tests have shown that the actual efficiency at which the energy in the fuel is converted to power is the same for Biodiesel and petroleum-based diesel fuel reference (Van Gerpen et al., 2004).

Table 2: Comparison of energy content of conventional diesel and biodiesel from soybean
Energy Content
Type of Fuel
Specific gravity GJ/ton GJ/m

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Specific Gravity</th>
<th>GJ/ton</th>
<th>GJ/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 2 Diesel</td>
<td>0.84</td>
<td>42.7</td>
<td>36</td>
</tr>
<tr>
<td>Biodiesel (soybean)</td>
<td>0.88</td>
<td>37.5</td>
<td>33</td>
</tr>
<tr>
<td>Petrol</td>
<td>0.75</td>
<td>43.8</td>
<td></td>
</tr>
<tr>
<td>Bioethanol</td>
<td>0.79</td>
<td>26.7</td>
<td></td>
</tr>
</tbody>
</table>

% of Biodiesel to No.2 Diesel

(-12.5%) (-8%)

Source: Adopted from (Van Gerpen et al., 2004)

Moreover, a fuel with lower energy content per gallon will cause the engine to produce less power. In this context biodiesel fuels contain fatty acids with different levels of unsaturation and fuels with more unsaturation tend to have slightly lower energy contents while those with greater saturation tend to have higher energy content (NIN, 1994; ASTM, 2002, EN, 2003).

2.4.9.3 Cold flow properties
Saturated fatty compounds have significantly higher melting points than unsaturated fatty compounds and in a mixture they crystallize at higher temperature than the unsaturated ones (Knothe, 2005). Thus Biodiesel fuels derived from fats or oils with significant amounts of saturated fatty compounds will display higher cloud points (CP) and pour points (PP), which are the major problems associated with the use of Biodiesel in low temperature areas or seasons. In such situations, solids and crystals rapidly grow and agglomerate, clogging fuel lines and filters (fuel filter plugging point (FFPP)) and causing major operability problems (Knothe and Dunn, 2001).

Specifications related to low-temperature properties are included in Biodiesel standards, as CP (ASTM D2500), PP (ASTM D97), CFPP (European standard EN 116) and low-temperature flow test (LTFT) (ASTM D4539) (ASTM, 1999; EN, 2003), but a limit is not given for these properties, rather a report is required. Therefore, each country can select one of two options for seasonal classes (summer and winter) and modify this specification based on national meteorological data (Knothe, 2005).

2.4.9.4 The Boiling range
The degree of saturation of the fatty acids attached to the glycerol backbone determines the boiling point of the triglyceride. Generally, the FAMEs, which are mainly comprised of carbon chain lengths from 16 to 18, have boiling points in the range of 330–357 oC; thus the specification value of 360 oC is easily achieved (Azam et al., 2005).
How ever, the boiling ranges of the Biodiesels is at the upper end of the range of diesel, within a fairly limited range, around 315-357 o C, that has effect on the formation of coke and also indicates greater amount of energy required to vaporize the Biodiesels. The FAMEs of carbon chain exceeding the specification may also not meet the specification of 90/95% boiling point limit of 360 o C specified in ASTM D6751 and in other Biodiesel standards (Kinast, 2003). Similarly, as per the specification of ASTMPS121-99, the chain length should be comprised of C 12 â€“C 22 FAMEs (ASTM, 1999).

2.4.9.5 Oxidative stability
Although the presence of unsaturated fatty acid component in fatty acid methyl esters (FAMEs) is required to some extent, as it restricts the FAMEs from solidification, (Khan, 2002), with high degree of unsaturation, FAMEs are not suitable for biodiesel as the unsaturated molecules react with atmospheric oxygen and are converted to peroxide. As a result, cross-linking at the unsaturation site can occur and the material may get polymerized, at high temperature, into very large agglomerations or a plastic-like body (Khan, 2002; Azam et al., 2005). The reason for autoxidation is the presence of double bonds in the chains of many fatty compounds. The autoxidation of unsaturated fatty compounds proceeds with different rates depending on the number and position of double bonds (Frankel, 1998).

To avoid this situation, European standards have set a minimum limit (≤ 120) of iodine value (IV) in their specifications (EN, 2003) (Appendix: 2). According to this specification, the concentration of linolenic acid and acid containing four double bonds in FAMEs should not exceed the limit of 12% and 1%, respectively (EN, 2003).

The fact is that, the positions allylic to double bonds are especially susceptible to oxidation. The bis-allylic positions in common polyunsaturated fatty acids such as linoleic acid (double bonds at D9 and D12, giving one bis-allylic position at C-11) and linolenic acid (double bonds at D9, D12, and D15, giving two bis-allylic positions at C-11 and C-14), are even more prone to autoxidation than allylic positions. The species formed during the oxidation process cause the fuel to eventually deteriorate. Factors such as presence of air, elevated temperatures or presence of metals facilitate oxidation. And metals have strong catalyzing effect on oxidation with copper showing the strongest effect (Knothe and Dunn, 2003).

Hence, the peroxide value (ASTM D 3703) denotes the milliequivalent of peroxide-bound oxygen in a 1000 g sample, and gives an indication of the extent of dynamic oxidative damage. The initial products of oxidation are hydroperoxides, which can then induce polymerization, forming insoluble gums and sediments (Erickson, 1995).
2.4.9.6 Kinematic viscosity
The injection droplet size is dependent on a number of properties including viscosity and surface tension (Graboski et al., 1999). It is the resistance to flow of a fluid under gravity. Viscosity increases with chain length and with increasing degree of saturation (Van Gerpen et al., 2004). Factors such as double bond configurations (cis double bond configuration giving a lower viscosity than trans) also influence viscosity while double bond position affects viscosity less. Viscosity affects the atomization of a fuel upon injection into the combustion chamber and thereby ultimately the formation of engine deposits (Knothe, 2002). The viscosity of a transesterified oil, biodiesel, is about an order of magnitude lower than that of the parent oil.

Kinematic viscosity has been included in biodiesel standards
(1.9â€“6.0 mm
2
/s in ASTM D6751 and 3.5â€“5.0 mm
2
/s in EN 14214). It can be determined by standards such as ASTM D445 or ISO 3104 (Gouw et al., 1966).

2.4.9.7 Specific Gravity
It is the ratio of the density of the substance, \( \bar{\rho} \), to a reference density, \( \bar{\rho}_{\text{ref}} \) (water- g/cm
3
).
\[
SG = \frac{\bar{\rho}}{\bar{\rho}_{\text{ref}}}
\]
The SG of most vegetables oils range between 0.860 -0.900 and oils that are denser contain more energy per liter (EN 14214) (EN, 2003). While, according to Clark (1988) low relative density was characteristic of predominantly parafinic fuel with good ignition properties in diesel engines, while high relative density indicated mainly aromatic or asphaltic fuel with poor combustion properties.

20
2.4.9.8 Iodine Value (IV)
Is a measure of total unsaturation (double bonds) within the FAME product. Iodine absorption occurs at double bond positions - thus a higher IV indicates a higher quantity of double bonds (unsaturated fatty acids) in the sample and greater potential to polymerize (in the engine) and hence lesser stability (Korus and Mousetis, 1984). The process of transesterification reduces the iodine value to a small extent (Stability of Bio-diesel, 2007; Prankl et al., 1999).

2.4.9.9 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 â€œflammableâ€ and â€œcombustibleâ€ materials. Higher values indicate materials that are less likely to ignite accidentally. ASTM D 974 and ASTM D 93 require a minimum of 52
\( ^{\circ} \)C for diesel and 130
\( ^{\circ} \)C for biodiesel (Kinast, 2003).
2.4.10 Environmental impacts of biodiesels

Apparently vegetable oils have been gaining worldwide attention as an alternative energy source because they are environment-friendly and renewable in nature. In contrast to conventional diesel, biodiesel creates substantial reduction in emission, hence, these properties make Biodiesel a good alternative fuel to petroleum-based diesel oil (Bol et al., 2004; Azam et al., 2005).

Biodiesel has many other environmental benefits, such as it is biodegradable, non-toxic, has a low emission profile (including potential carcinogens) (Ma and Hanna, 1999; Khan, 2002; Azam et al., 2005; Zheng et al., 2006).

It can be used in today’s vehicle fleets worldwide and may also offer a viable path to sustainable transportation, i.e., lower greenhouse gas emissions and enhanced mobility, even in remote areas (Francis et al., 2005). Moreover since the primary feedstock for Biodiesel is a biologically-based material that can be grown season after season, it is renewable. And, since the carbon in the fuel was originally removed from the air by plants, there is no net increase in carbon dioxide levels (Peterson and Hustrulid, 1998; Van Gerpen et al., 2004).

Biodiesel is safer fuel as it has higher flash point (FP) temperature, and regarded as clean fuel since it has almost no sulphur (Table 3) and aromatics, less pollutant to water and soil than that of petroleum diesel fuel (Sharp, 1998; University of Idaho, 1996).

Table 3: Properties of Diesel, biodiesel blend (B20) and biodiesel (B100)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Diesel</th>
<th>B20</th>
<th>B100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cetane number</td>
<td>43.3</td>
<td>46</td>
<td>47.5</td>
</tr>
<tr>
<td>Flash point (°C)</td>
<td>62</td>
<td>90</td>
<td>146</td>
</tr>
<tr>
<td>Sulphur wt (%)</td>
<td>0.0476</td>
<td>0.037</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Source: (Sharp, 1998)

It is the most suitable fuel in environmentally sensitive areas (national parks, lakes, rivers) or in confined areas where environmental conditions and worker protection must meet high standards (underground mines, quarries) (Neeft et al., 1996; Howell and Weber, 1997). Moreover, it contains about 10% built in oxygen, which helps it to burn fully and also expected to reduce exhaust emissions. Its higher cetane number (CN) improves the ignition quality even when blended with petroleum diesel (Graboski and McCormick, 1998; Subramanian et al., 2005).

Nevertheless, diesel engines are significant contributors of nitrogen oxides (NOx) and particulate matters (PM)

10 -condensed or solid material /\%_{w}^{\leq}10.0/\%_{m}/ collected on an appropriate filter at a temperature of 52 °C or lower to ambient air pollutant inventories (USEPA, 2003). Hence, the important property of Biodiesel is, then, its ability to reduce...
such pollutants as total PM, carbon monoxide (CO) and total hydrocarbon (THC) emissions from an engine (McCormick et al., 2001). Studies also showed significantly lower levels of emissions of specific toxic compounds for Biodiesel and Biodiesel blends, including aldehydes, polyaromatic hydrocarbons (PAH), and nitro-polyaromatic hydrocarbons (nPAH) (Sharp et al., 2000; NBB, 2004).

Recent combustion tests, by Brookhaven National Laboratory, indicated that blends of heating oil and Biodiesel fuel can lower nitrogen oxide (NOx) emissions from residential oil burners by 10 percent to 20 percent when compared to conventional distillate fuel oil (Batey, 2003). Substantial reduction in CO emission (Peterson et al., 1998), 13-66% reduction in PM (Graboski and McCormick, 1998; USEPA, 2003) as well as significant reduction in sulphate emission etc. were also reported (Sharp et al., 2000; Cardone et al., 2003; NBB, 2004).

2.4.10.1 The effect of fatty acid composition on emissions
The experiments conducted on emission and consumption measurements, by Kalligeros et al. (2003) under various loads using marine diesel fuel, and two types of biodiesels (sunflower oil and olive oil) in various proportions confirmed the decrease in CO, HC, NOx and PM. This is due to the oxygen contained in the biodiesel molecules and the low levels of sulfur content emissions (Kalligeros et al., 2003; Batey, 2003).

Peterson et al. (2000), reported on six different vegetable oil esters (coconut ethyl ester, used hydrogenated soy methyl ester, rapeseed ethyl ester, mustard ethyl ester, safflower ethyl ester, and a commercial methyl ester of soy oil) to represent a range of iodine numbers from 7.88 to 133 indicated that, lower iodine numbers were correlated with reduced nitrogen oxides (NOx). As iodine number increased from 7.88 to 129.5 the NOx increased 29.3%. Fatty acids with two double bonds appeared to have more effect on increasing NOx emissions than did fatty acids with one double bond (Peterson et al., 2000).

The reason for the decrease in NOx, was that the cetane numbers of the biodiesels were higher than that for the diesel fuel, and this is usually associated with lower NOx emissions, (Monyem and Gerpen, 2001). Increasing cetane number reduces the size of the premixed combustion by reducing the ignition delay. This results in lower NOx formation rates since the combustion pressure rises more slowly, giving more time for cooling through heat transfer and dilution and leading to lower localized gas temperatures (Lee et al., 1998). In this regard, the cetane number of olive oil being higher than for the sunflower oil, resulted in greater reduction of NOx emissions, when olive oil biodiesel was used (Kalligeros et al., 2003).

The aromatic and polyaromatic hydrocarbons (HCs) are also responsible for high NOx
emissions. This is probably due to the higher flame temperatures associated with aromatic compounds. By reducing aromatics the flame temperature will drop, leading to a lower NO\textsubscript{X} production rate. As a result, the addition of biodiesel which does not contain the above classes of compounds, reduces the NO\textsubscript{X} emissions from the engines. The aromatics have high carbon–hydrogen ratios and thus fuels with lower aromatics will lead to a smaller amount of CO\textsubscript{2} and larger amount of H\textsubscript{2}O being formed compared to high aromatic fuels (McCarthy et al., 1992; Lange et al., 1993; Ulman et al., 1994; Spreen et al., 1995; Martin et al., 1997; Straddling et al., 1997). On the other hand, forcing more oxygen into the chamber increases the efficiency of the combustion process, reduces emissions, and increases performance (DTF; MECT; U.S EPA, 2007).

Nevertheless, even though the experiment conducted on soybiodiesel indicated similar reduction in PM, slight increase in NO\textsubscript{X} emissions has been observed. Graboski and McCormick (1998) reported 13â€“66% reduction in PM with 2â€“11% increase in NO\textsubscript{X} (Graboski and McCormick, 1998).

23
2.5 Description of some selected oil bearing plants for bio-diesel production in Ethiopia
2.5.1 Castor (Ricinus communis L.)
Family: Euphorbiaceae
Genus: Ricinus
Species: R. communis
Vernacular name in Ethiopia: â€˜Guloâ€™ (in Amharic (A)) and â€˜Qobbooâ€™ (in Oromo language (O))

General Description
R. communis (the only species of the monotypic genus Ricinus) belongs to the Euphorbiaceae, or spurge, family, containing a vast number of plants native to tropics (where it grows wild and considered as merely a weed or as a shade-giving agent for more sensitive low growing cash crops). It is a warm-season plant indigenous to eastern Africa and probably originated in Ethiopia (UNIDO, 1974; Onwueme and Sinha, 1991; Desai, 2004).

It is herbaceous annals, with height displayed as genetically dwarf, semi-dwarf or tall ranging from one to several meters (Atsmon, 1989), and warm region perennial (with cultivation area between 40\degree N and 40\degree S), but is now cultivated up to 52\degree N (Seegeler, 1983). Castor can survive under rather dry conditions because of its very strong root system, its resistance to loss and its ability to withstand substantial water stress. As a peasant crop in the warmer regions of the world, castor can be grown almost anywhere if
land is available, and this is perhaps its greatest virtue (the castor plant can be considered as an easily cultivated, adaptable cash crop, on well drained soils in frost-free seasons (Atsmon, 1989). It grows best in areas with clear sunny days and without untimely frosts. In such circumstances, it grows from sea level at the coast to high inland mountains. One of the reasons that castor plants have become so successful is their extremely viable seed that germinates readily in a variety of soils. More often castor is inter-planted with crops, sown round the borders and margins of fields on areas unsuitable for other crops (Seegeler, 1983; Anderson et al., 2004).

Varieties of castor should be grown at distances of at least 30 m from each other, since it is subject to cross pollination, and that open pollination may cause differences in the size and degree of maturity of the pods and seeds formed on the same plant. The most favorable rate of annual rainfall requirement is from 500 to 800 mm (UNIDO, 1974; Atsmon, 1989), and any altitude from sea level to 1500 masl. The plant can grow well on very poor soil; whilst a very fertile soil may even render a lower yield of seed (chemical fertilization for castor is not normally recommended (Atsmon, 1989)).

The common seed yield was from 1000 to 1,500 kg per ha, while new varieties obtained with yield of 5,000 to 6,000 kg per ha and 50 to 52 percent oil content. The castor meal is poisonous, since it contains the toxic protein ricin, the effect of which drives from dissolution of erythrocytes, it is even more poisonous than hydrocyanic acid. The oil after pressing and/or extraction is definitely free from any toxic ingredients. The unique characteristics of castor derives from itä€™s nearly 90% ricinoleic acid (C

$$\text{C}_{17}\text{H}_{32}\text{OHCOOH}$$

content. It has highest viscosity and highest density of all oils (UNIDO, 1974).

Castor has numerous industrial uses, namely; for production of paints, and varnishes, nylon type synthetic polymers, resins and lubricants, cosmetics, textile dyeing, insecticides, in leather industry as well as for medicinal purposes-as a laxative. Leaves of the castor plants have been used for feeding silkworms and cattle, as human food (where fresh green food is scarce), the branches and stem can be used for the production of low grade paper as well as for fuel. The residual meal after oil extraction contains 5% nitrogen that used as a fertilizer, and 30-45% protein that, if detoxified, can be used as a feed (Atsmon, 1989). It is the only oilseed used in Ethiopia for lighting. The people in the rural made a hole in a seed and threaded 9 or 10 on thin sticks of wood, 15 cm long. The seed on top is lit and fire creeps slowly downwards (Seegeler, 1983).

Major diseases of castor are bacterial leaf spot, caused by Xanthosomonas ricinicola and cotton root rot, caused by Phymatotrichum omnivorum. While Insect pests are caterpillars of Arhaea janata and Diochocrosis punctiferalis. Regions of high rainfall are more affected while there is no serious problem in dry areas (Onwueme and Sinha, 1991).

In Ethiopia research conducted by Getinet Alemaw et al., (2007) on genetic and agronomic studies on castor revealed that, out of 15 accessions tested for six testing environments, the genotype coded 106376 rendered highest seed yield (30.60 Q/ha), at Arba Minch (Table 4). This variety has been named ä€˜Abaroä€™ and released in 2007.
Table 4: Seed Yield (Q/ha), oil content (%w/w) and Seed weight (g/1000) of Castor (Abaro) (2004-2006) at six locations

<table>
<thead>
<tr>
<th>Description</th>
<th>Awassa</th>
<th>Arba Minch</th>
<th>Wondo Genet</th>
<th>Wondo Genet</th>
<th>Bako</th>
<th>Fenote Selam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Seed Yield</td>
<td>13.80</td>
<td>30.60</td>
<td>17.10</td>
<td>17.80</td>
<td>18.90</td>
<td>19.80</td>
</tr>
<tr>
<td>Oil content</td>
<td>46.6</td>
<td>47.3</td>
<td>52.6</td>
<td>42.3</td>
<td>41.9</td>
<td></td>
</tr>
<tr>
<td>Seed weight</td>
<td>502</td>
<td>847</td>
<td>514</td>
<td>611</td>
<td>533</td>
<td>506</td>
</tr>
</tbody>
</table>

Source: Adopted from (Getinet Alemaw et al., 2007)

"Abaro" has distinguished agronomic and quality traits as depicted in (Table 5) and the recommended ecological zones of adaptation is shown in (Table 6).

Table 5: Mean agronomic and quality traits that distinguish "Abaro" from others

<table>
<thead>
<tr>
<th>Morphological traits</th>
<th>Description</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf color</td>
<td>Purple</td>
<td>Stable</td>
</tr>
<tr>
<td>Stem color</td>
<td>Purple</td>
<td>Stable</td>
</tr>
<tr>
<td>Leaf size</td>
<td>Large</td>
<td>Stable</td>
</tr>
<tr>
<td>Branching habit</td>
<td>Mid height</td>
<td>Stable</td>
</tr>
<tr>
<td>Inflorescence</td>
<td>Purple</td>
<td>Stable</td>
</tr>
<tr>
<td>Plant height</td>
<td>2.7 meter</td>
<td>Stable</td>
</tr>
<tr>
<td>Seed color</td>
<td>Dark black</td>
<td>Stable</td>
</tr>
<tr>
<td>Seed size</td>
<td>Bold, large</td>
<td>Stable</td>
</tr>
<tr>
<td>Seed weight</td>
<td>502 to 847</td>
<td>Stable</td>
</tr>
</tbody>
</table>

Source: (Getinet Alemaw et al., 2007).

In conclusion, castor is tolerant to moisture stress and hence can be a good alternative crop in Rift valley and Eastern part of Ethiopia. It is also an excellent rotation crop for maize, sorghum, pulses and horticultural crops; hence, production should be encouraged as the return is also much higher than for maize and sorghum (Getinet Alemaw et al., 2007).

Table 6: Recommended Ecological Zones of Adaptation suitable for castor (Abaro) plantation

<table>
<thead>
<tr>
<th>Length of growing period</th>
</tr>
</thead>
<tbody>
<tr>
<td>140-190 days</td>
</tr>
</tbody>
</table>

Soil type Sandy loam pH 5-6.5
Rainfall 400-500 and 600-900 for clay soil
Altitude 1200-2000 masl
Temperature 20-26°C

Major growing areas Rift valley, North Eastern Ethiopia particularly Kobo and Cheffä areas, Eastern Ethiopia sorghum growing areas

Source: (Getinet Alemaw et al., 2007).
2.5.2 Ethiopian Mustard (Brassica carinata Braun)

Family: Brassicaceae
Genus: Brassica
Species: carinata

Vernacular name in Ethiopia: â€˜Yehabesha gommenzerâ€™ (A), â€˜Ija raafuuâ€™ (O)

General Description
B. carinata (Ethiopian mustard, Abyssinian cabbage) originated in Ethiopia where it is cultivated and used both as a leaf vegetable and as an oilseed crop, it is known to be highly heat and drought tolerant (Braun, 2000). B. carinata is the main indigenous oil and vegetable crop of Ethiopia. It may be both yellow and brown seeded. It is a natural amphidiploid of female B. nigra and male B. oleracea (Downey and Robbelien, 1989; Smith et al., 1997), i.e., it is believed to have originated as a result of hybridization between B. nigra and B. oleracea growing wild in nature (Prakash and Chopra, 1990). Relating color and origin of the samples suggests that reddish brown is most frequent in east and north Ethiopia. Grayish light-brown is relatively frequent in south-western Ethiopia (Seegeler, 1983).

Mustards tend to have a higher tolerance to water stress, insect pests and diseases. Yields have often been better than for canola especially in drier areas. The highly variable Ethiopian mustard is almost completely immune to blackleg. The oil of some of the lines contains a very high proportion of erucic acid, which gives them potential as industrial oil or for biodiesel fuel. Ethiopian mustard produces a lot of biomass, more than any of the other mustards. Their leaves can vary from a bluish-green to a deep burgundy (Gouw and Vlugter, 1966).

In Ethiopia there are two types of Brassica species cultivated. These are B. carinata and exotic rape seed (Brassica napus). B. carinata is widely cultivated in the high land and semi-highland part of the country, while better yield is registered at an altitude ranging from 2000-2600 masl. And it prefers low temperature (mean about 20°C) with average rainfall of 500 to 650 mm. It prefers well drained heavy type of sandy loam or a light clay soil, with pH between 6 to 7.5. It is a good rotation crop for cereals and pulses and seed yield of up to 3000 kg/ha, on demonstration plots, were achieved (Getinet Alemaw and Negusse Alamayehu, 1997).

There have been several varieties released by the agricultural research centers among which MS-YD X Zem-1-BCR-5 (Holetta-1), Yellow Dodola and S-67 (released by HARC/EARO), Muger (PGRC/E 2002) and Tule (PGRC/E 21163) (released by ARARI/ADARC) as well as Shaya (S-67X zem-1/xs-67c6) (released by EARO/ AWARC). Other varieties like Acc. 153 (Hawassa I) and PGRC/E/1/208507 (Hawassa II) are also recently released by the AWARC/SARI (MoARD, 2005).

According to MoARD (2005) Crop Variety Register, the seed yield per hectare and oil content of these varieties vary ranging from 940 to 3030 Kg/ha (on research field) and oil content from 355 to 1184 Kg/ha. Table B3 (Appendix 10) elaborates the detailed agronomic and morphological characteristics of different varieties of B. carinata.

Nevertheless, B. carinata, due to its limited distribution to Ethiopia and neighboring...
countries (where the parental species B. nigra and B. oleracea were sympatric), has had little exposure to modern plant improvement, although its vigor, drought, insect and disease tolerance has recently gained recognition. In Ethiopia, since the oil of B. carinata is composed of about 40% erucic acid and the meal contains 69.8 to 158 μmole/g sulphur compound called glucosinolates (2-propenyl glucosinolate), the oil has no recommended quality for food and feed (Downey and Robbelen, 1989).

2.5.3 Physic nut (Jatropha curcas L.)
Family: Euphorbiaceae
Genus: Jatropha
Species: curcas
Vernacular name in Ethiopia: Ayiderke, Yedinber shimaglle (A), Qobboo faranjii (O), Tsedaki (Gofa Sawula in SNNPR)

General Description
In Ethiopia there is no any research conducted regarding the distribution and use of the plant. However, according to the information obtained from the National Herbarium, at Addis Ababa University, J. curcas is naturalized at different places in Ethiopia. Samples were collected from areas like, Shawa-Metehara, Illubabor, Bale-Dello Mena, Wello-Ambasel and Gojam- Ketetya and Gerba. The plant is shrub, 2 to 4.5m high and used in rural areas as a hedge.

However, different literatures emphasize that, J. curcas is a low- growing tree, native to South America, but widely cultivated also throughout Central America, Africa and Asia. (Mühlbauer et al, 1998). It was probably distributed by Portuguese seafarers via the Cape Verde Islands and former Portuguese Guinea (now Guinea Bissau) to other countries in Africa and Asia in the 16th century (BAZ, 2007). It is one of the main crops currently being promoted for biodiesel production in several countries, globally. Its English name is physic nut, purging nut, pulghere (Harvesting clean energy, 2006). J. curcas grows as a shrub or tree, from sea level to 1700 masl and requires average annual rainfall of between (300 to 1000 mm). It is adapted to higer temperature (20 o C up to 28 o C). It is propagated by cuttings and seeds (Joachim, 1996).

There are 170 known species of genus Jatropha. As its name derived from the Greek jatrÃ’s (doctor), trophÃ© (food), the plant implies medicinal uses (Mühlbauer et al., 1998). However, its oil is inedible due to the presence of toxic lectin and phorbolesters (MartÃnez-Herrera et al., 2006). As Jatropha is not browsed by animals, it has historically been planted as a living hedge/fence by farmers all over the world around homesteads, gardens and fields, protecting cropland from freely ranging cattle, sheep and goats. It is a vigorous, drought and pest-resistant plant, its cultivation requires simple technology, and comparatively modest capital investment, but in its infancy can have enemies such as giant grasshoppers, termites, leaf miners, fungal diseases, and beetles (Mühlbauer et al., 1998; BAZ, 2007). Jatropha curcas grows almost anywhere â€“ even on gravelly, sandy and saline soils. It can thrive on the poorest stony soil and even in the crevices of rocks (Jyot et al., 2007).
This plant is a vigorous bush with soft wood, 1-8m tall. It has a straight stem with gray or reddish bark, with wide white spots. Like many other jatropha species, physic nut is a succulent that sheds its leaves during the dry season. It is therefore, best adapted to arid and semi-arid conditions. Its water requirement is extremely low and it can stand long periods of drought by shedding most of its leaves to reduce transpiration loss. Hence, most jatropha species occur in the seasonally dry areas; grassland-savanna (cerrado), thorn forests scrub and caatingas vegetation (Seegeler, 1983; Jyot et al., 2007).

Jatropha is a valuable multi-purpose crop to alleviate soil degradation, desertification and deforestation, which can be used for bio-energy to replace petrodiesel, for soap production and climatic protection, and hence deserves specific attention. Jatropha can help to increase rural incomes, self-sustainability and alleviate poverty for women, elderly, children and men, tribal communities, and small farmers. It can as well help to increase income from plantations and agro-industries (Mühlbauer et al., 1998).

Jatropha enthusiasts refer to this as the Jatropha System, which has four equal aspects; Renewable energy, Erosion control, Women promotion and Rural income â€“ all of which can be achieved through Jatropha cultivation (BAZ, 2007). The non-toxic varieties of Jatropha can be used as fodder for animals or as high quality fertilizer reducing the costs for buying fodder and mineral fertilizers, respectively. The press cake of toxic varieties is limited to the use as fertilizer. J. curcas produces seed with total oil content of 37-58%. The seed yield reported for Jatropha varies from 0.5 to 12 T/year/ ha- depending on soil, nutrient and rainfall conditions and the tree has a productive life of 30 years (Mühlbauer et al., 1998). Subramanian et al. (2005) also reported oil yield of 46-58% from kernel and 30-40% of seed weight in India.

Research conducted in Nicaragua indicates that production per 1000 ha/a, yield; 1500-1700 tonnes oil (half of which is refined into biodiesel), 1600 ton press cake (sold as animal feed after detoxification), 144 ton Glycerol (sold to pharma and cosmetic producers). The energy balance ratio, i.e., invested energy to product, is 1:3.75-5, and 100 ha J. curcas create 840 temporary jobs (6-7 months per year) and 45 permanent jobs (Jatropha c., 2006).

From the experience in India and elsewhere, a plant density of 2,500 per hectare (spacing of 2 X 2 meters) has been found to be optimal, while in rain-fed areas on poor soils a lower plant density of 1,666 has been felt to be more desirable. If planted in hedges, the reported productivity of Jatropha is from 0.8 kg to 1.0 kg of seed per meter of live fence, and assuming a square plot (1 ha), a fence around it will have a length of 400 sq. meters and a production of 0.4 ton of seed (Jyot et al., 2007).

Moreover, the biofuels Association of Zambia (BAZ) reported that, Jatropha is not listed among the invasive plants of Southern Africa. The plant is not a weed and is not self-propagating, but has to be planted. It grows in areas of as low rainfall as 300 mm and withstands long drought periods. It is easy to establish, grows relatively quickly, and is hardy. Jatropha plant does not threaten food crops and is used in stabilization of soils, erosion control, reclamation of arid and semi-arid lands, as hedge control for livestock, and propping support for plants such as vanilla plant (BAZ, 2007).
Oil Palm (Elaeis guineensis Jacq.)

Family: Palmae
Genus: Elaeis
Species: guineensis

Vernacular name in Ethiopia: 'Zanbabaë™ (A), â€œMeexxiâ€™ (O)

The oil palm was originated in West Africa but has been planted successfully in tropical regions within 20 degrees of the equator. There are two species of oil palm, the better known one is the one originating from Guinea, Africa and was first illustrated by Nicholaas Jacquin in 1763, hence its name, Elaeis guineensis Jacq. Mature trees are single-stemmed, and grow to 20-30 m tall. The oil palm is a tree which comes into fruit 4-6 years after transplanting, and may continue to bear fruit for 50 years (Onwueme and Sinha, 1991). Each fruit is almost spherical, ovoid or elongated in shape. Generally the fruit is dark purple, almost black before it ripens and orange red when ripe (Oil palm, 2007).

The fruit grows in a large bunches that can weigh between 10 to 40 kilograms each. Each fruit contains a single seed (the palm kernel) that contain 50% oil protected by a wooden endocarp or shell surrounded by a soft oily mesocarp or pulp. Fruit bunches contain typically 20-24% (w/w) of palm oil and 2-3% (w/w) of palm kernel oil that can be extracted. The high productivity of the oil palm at producing 5-7 tonnes of oil (as high as 7,250 liters per hectare per year) has made it the prime source of vegetable oil for many tropical countries. The residue after extraction (palm kernel cake) is rich in carbohydrate (48%) and protein (19%), and is used as cattle feeds. The ash remaining when the bunch refuse is burnt is rich in potash and is used to make soap (Gascon et al., 1989; Palm oil, 2007).

The best quality palm oil has a free fatty acid (FFA) content of around 3.5%, while the poor quality oil obtained by using traditional methods may contain as much as 85% FFA. Rapid removal of the fruit from the bunch is required, as removal by natural course may take a week, and this will considerably increase the FFA content (Onwueme and Sinha, 1991; Palm oil, 2007).

Oil palms require adequate light and soil moisture. It can tolerate temporary flooding, provided the water is not stagnant. It flourishes well in areas with an annual rainfall averaging 2,000 mm or more distributed evenly throughout the year. A high level of solar radiation (at least five hours of sunshine per day) is important for growth and bunch production. A mean maximum of 30-32°C and a mean minimum of 21-24°C are the most suitable temperatures. The water-holding capacity of the soil is more important. Oil palm can be grown on a wide range of tropical soils as well as a wide range of pH (mostly 4-6), except on waterlogged and very sandy, stony or peaty soils (Onwueme and Sinha, 1991; Palm oil, 2007).

The main diseases of oil palms are blast (caused by Pythium splendens and Rhisoctonia lamellifera), freckle (caused by Carcospora elaeidis) and anthracnose (caused by Batryodiplodia palmarum) and insect pests are palm weevils (Rhynchophorus phoenicis and Orcytes owariensis), leaf miners (Coelaenomenodera elaeidis) and slug caterpillars (Parasa viridissima) (Onwueme and Sinha, 1991).
III. MATERIALS AND METHODS
3.1 Sample collection and area suitability assessment
3.1.1 Sample collection
Samples of the oilseeds were collected from different locations, namely; R. communis from Awassa & Wendo Genet (Awassa wereda), B. Carinata from Assela (Tiyyo wereda), E. guineensis (oil) from Teppi Coffee farm (Godere wereda) and J. curcas from Upper Awash (Boset & Jeju weredas) (Table 7 & Figure 10). Sample collection was based up on agroecological diversification of the country, pertinent to altitudinal requirements of each; while conventional No. 2 diesel fuel was purchased from fuel station in Addis Ababa, for comparative analysis with the biodiesels.

Table 7: Types and locations of the samples of oilseeds collected

<table>
<thead>
<tr>
<th>No.</th>
<th>Oilseeds Species</th>
<th>Common name</th>
<th>Location Variety</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ricinus communis</td>
<td>Castor</td>
<td>Wondo Genet and Awassa (Agricultural Research Center)</td>
<td>Abaro, others from field trial</td>
</tr>
<tr>
<td>2</td>
<td>Brassica carinata</td>
<td>Ethiopian Mustard</td>
<td>Asella (Ethiopian Grain Trade Enterprise)</td>
<td>Yellow Dodola</td>
</tr>
<tr>
<td>3</td>
<td>Elaeis guineensis (oil)</td>
<td>Palm</td>
<td>Teppi (Coffee farm)</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Jatropha curcas</td>
<td>Physic nut</td>
<td>East Shewa &amp; North West Arsi (Bofa, Doni, Tibila areas)</td>
<td>Semi wild/hedge</td>
</tr>
<tr>
<td>5</td>
<td>No.2 Diesel</td>
<td>Diesel Fuel station</td>
<td>(Addis Ababa)</td>
<td>(Variety not investigated)</td>
</tr>
</tbody>
</table>
3.1.2 Delineation of agroecological suitability areas
The agricultural requirements were investigated using information available at various agricultural research centers in the country as; Awassa, Kulumsa, EORC and Holetta research centers. Moreover, review of literatures, field investigations and interviews to the local communities were conducted using questionnaires. Area suitability assessment was carried out and the country's different agroecological zones were delineated based up on the agroclimatic requirements, respective to the aforementioned oil plants. From the existing Ethio GIS data Ethio DEM (Digital Elevation Model) were taken and reclassified based on the criteria prepared for analysis purpose, in ArcGIS software using the special analyst tool. Finally, Ethio zones map were overlaid on the analysis result. The elevation values classified based on the criteria set from the 5 traditional agroclimatic classifications of Ethiopia, according to MoA (2000) as depicted in (Appendix 6), was applied as reference.

3.2 Experimental
Experiments were conducted in a laboratory-scale setup developed at Addis Ababa University-Department of Chemistry (AAU-DC) and Essential Oils Research Center (EORC) laboratories, while fuels' physico-chemical properties were analyzed at Ethiopian Petroleum Enterprise (EPE) Quality Control Laboratory and calorific value was tested at Geological Survey of Ethiopia Central Laboratory. All chemicals used in the experiments such as methanol and Ethanol (99.5%) and sulfuric acid (99% pure) were of analytical reagent (AR) grade. The KOH and NaOH in pellet form were used as a base catalyst for transesterification reaction.

3.2.1 Seed Preparation
Various processes were required in the course of oilseeds preparation, which included; samples clearing, drying- to a constant weight in order to reduce its moisture content to less than 10% and grinding- in order to weaken or rupture the cell walls to release vegetable fat for extraction (Akpan, 2006).

3.2.2 Determination of Moisture Content of the Seeds
Plate weight was noted primarily, and then sample weight (of the ground sample with plate
5-7g) was taken and dried in an oven at 105°C for 7 hs and the final weight was taken. The procedure was repeated in triplicate and recorded (Appendix 10). The percentage moisture in the seed was calculated using (Eq 1):

34
Moisture Content = [(W1- W2)/(W1-Wp)]100
%

Where, W
1
= Original weight of the sample (with plate) before drying,
W
2
= Weight of the sample (with plate) after drying,
W
p
= Plate weight,
3.2.3 Oil extraction and determination of the seed oil content (% w/w)

Oil extraction was conducted at the two laboratories (AAU-DC and EORC). Soxhlet extraction method (Horowitz, 1984), with n-hexane as extracting solvent was used. Each extraction was proceeded for 4 hrs. It was then removed from the apparatus, cooled in the desiccators and solvent removed using rotavapor (BUCHI). The experiment was repeated in triplicate. The weight of oil extracted was determined for each replicate, and the mean value was recorded (Appendix 10) and the percentage of oil extracted was determined using (Eq 2). Sample weight was taken dry base, based on the moisture content determined.

Seed Oil Content = [W
o
/W
s
] 100 %

Where, W
o
= Weight of oil extracted,
W
s
= Weight of sample (dry base),
3.2.4 Characterization of the extracted oil and the resulting biodiesels'™ physicochemical properties analysis [ASTM 1,2, 2002]
3.2.4.1 Determination of Acid Value (AV) or Acid number (AN) (ASTM 1, 2002)
Standard alcoholic KOH solution (0.1M) was prepared by dissolving 5.6g of KOH (pellet) 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)
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 (isopropyl alcohol) 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 oC, adding 0.1M KOH solution 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.

35 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_A), for the sample titration, and volume for the blank (V_B) were noted. Then:

The total acidity (Acid number- AN (mgKOH/g)) was calculated using (Eq 3):

\[ AN = \frac{(V_A - V_B) \times N \times 56.1}{W} \]  

Where, Wo = sample weight, 
V_A = Volume of KOH used for the sample (mL), 
V_B = Volume of KOH used for the blank (mL), 
N = Concentration of KOH used (Molar),

3.2.4.2 Determination of Iodine value (IV) 
Wijâ€™s Method was applied to determine IV (Cocks and Vanrede, 1976; PCAF, 1981; OMA, 1984; Lawson, 1985). The weighed amount (0.25g) of substance (W) was dissolved in 15 mL carbon tetrachloride in a conical flask. 25.00 mL of 0.2N Wijs solution (prepared by dissolving 9g of iodine trichloride in a mixture of 700mL glacial acetic acid (purity at least 99%) and 300mL carbon tetrachloride) was added from a burette. The flask was closed, mixed, and allowed to stand in the dark at about 20 oC for 1 hs. After standing, 20 mL potassium iodide solution and approximately 150 mL water were added. The iodine liberated by the process was titrated with sodium thiosulphate solution while shaking and starch indicator was added towards the end of titration (and volume V_a was recorded). Blank determination was made with the same quantities of reagents at the same time and
under the same conditions (and volume \( V_b \) was recorded). Finally the iodine value (IV) was calculated using (Eq 4).

\[
\text{(Eq. 4)}
\]

Where, \( W = \) weight (g) of sample taken

\[
V_a = \text{Volume (mL) of thiosulphate solution used in test}
\]

\[
V_b = \text{Volume (mL) of thiosulphate solution used in blank}
\]

\[
N = \text{Normality of thiosulphate solution}
\]

\[
IV = 12.69 \times N \times (V_a - V_b)
\]

\[
W
\]

36

3.2.4.3 Determination of Saponification Number (SN)
The SN determination was conducted by dissolving the fat or oil in an ethanol solution which contains a known excess of KOH. This solution is then heated so that the reaction goes to completion. The unreacted KOH is then determined by adding an indicator and titrating the sample with HCl (Cocks and Vanrede, 1976; PCAF, 1981; OMA, 1984; Lawson, 1985).

About 40g filtered oil (\( W \)) was weighed into a 200 mL conical flask with an accuracy of 1mg. 50 mL of 0.5N ethanolic potassium hydroxide solution was added to the cold oil and the reflux condenser attached to the flask. The mixture was heated, and as soon as the ethanol boils, the flask was occasionally shaken until the oil was completely dissolved, and the solution boiled for half an hour. After the oil was completely dissolved, 1mL phenolphthalein indicator was added and the hot soap solution obtained was slowly titrated with 0.5N hydrochloric acid (and volume \( V_a \) was recorded). And a blank determination was carried out upon the same quantity of potassium hydroxide solution at the same time and under the same conditions (and volume \( V_b \) was recorded). The final result was calculated using (Eq 5).

\[
\text{(Eq. 5)}
\]

Where, \( W = \) weight (g) of oil taken

\[
V_a = \text{Volume (ml) of hydrochloric acid used in test}
\]
3.2.4.4 Determination of Peroxide Value (PV)

In principle the peroxide value is determined by subjecting potassium iodide at room temperature to the oxidant effect of peroxides. The iodine thus liberated, is titrated with sodium thiosulphate (Cocks and Vanrede, 1976; PCAF, 1981; OMA, 1984; Lawson, 1985).

5g of sample was weighed with an accuracy to 5 mg into a 200 mL conical flask. 30mL of the solvent (2 volumes of glacial acetic acid and 1 volume of chloroform) was added and the air above the liquid was displaced with carbon dioxide. Then 1mL of the potassium iodide solution was added and a homogeneous solution resulted. The solution was allowed to stand in the dark for 1 min and 30 mL water was added. Then titrated with 0.02 N sodium thiosulphate solution using a few mL of starch solution as indicator (the volume V a recorded). A blank determination was simultaneously run and volume (V b ) noted. The result was calculated according to (Eq 6).

\[ SN = \frac{56.1 \times N \times (V_a - V_b)}{W} \]  

Where,  
\( W \) = Weight (in g) of sample.  
\( V_a \) = Volume (in mL) sodium thiosulphate used in test  
\( V_b \) = Volume (in mL) sodium thiosulphate used in blank  
\( N \) = Normality of sodium thiosulphate

3.2.5 Synthesizing a Biodiesel

3.2.5.1 Biodiesel from pure vegetable oil (PVO) (Freedman et al., 1984)

Measured volume of pure vegetable oil was warmed up to about 40Â°C in a beaker. 0.35% (w/v) of finely ground anhydrous KOH was added into 20% (v/v) pure (99% or higher purity) methanol 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 was dissolved. When all of the KOH was 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 or phosphoric acid. Then 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.

3.2.5.2 Biodiesel from oils with higher free fatty acid (FFA)

Oils with high FFA content (usually greater than 1% determined by standard titrimetry method) (ASTM 1, 2002), require pretreatment (esterification) for reduction of FFA of the oils below 1% (Ghadge and Raheman, 2005) before transesterification reactions. That is, FFAs were first converted to esters in a pretreatment process with methanol-to-oil ratio (0.28 v/v) using H\(_2\)SO\(_4\) as catalyst (1.43% v/v) in 88-min reaction time at 60\(^\circ\)C temperature. The product having acid value less than 2 +/- 0.25 mg KOH/g was used for the transesterification reaction, after neutralization with 3M NaOH in water for 15 min at 80\(^\circ\)C (Chongkhong et al, 2007).

The transesterification reaction was carried out with 0.25 v/v methanol-to-oil ratio (i.e., 6:1 molar ratio) using 0.55% w/v KOH as an alkaline catalyst. The amount of KOH (5.5mg) was reached based on the amount needed to neutralize the unreacted acids (i.e., 2 mg KOH/g) in the second stage product plus 0.35% for pure oil. The reaction was carried out at 60\(^\circ\)C for half an hour and the products were allowed to settle overnight before removing the glycerol layer from the bottom in a separating funnel to get the ester layer on the top (Srivastava and Prasad, 2000). Finally washed with 2.5 mL/L of phosphoric acid and then with hot water three times (Usta, 2005).

3.2.5.3 Determination of Fatty acid compositions -GC Analysis

The fatty acid compositions of the synthesized alkyl esters were determined by a well established GC procedure (Kemp, 1967). Standards of the methyl esters of the fatty acids (products of Aldrich Chem. Co.) were obtained from Essential Oils Research Center (EORC). The GC was calibrated by injecting standards at varying concentrations. Then, samples were injected (0.5 \(\mu\)L) one by one in a Dani GC 1000, equipped with a capillary column of EC TM-5 (25 m x 0.53 mm x 1 \(\mu\)m). The GC oven was primarily kept at 50\(^\circ\)C for 2 min, then heated at 4\(^\circ\)C/min.
C/min up to 250°C, where it was kept for 15 min, and a pressure of 1.25 Bar was applied. The detector was a flame ionization detector (FID), and the carrier gas was nitrogen at (1 mL/min).

3.2.5.4 Determination of Specific Gravity (SG) and Density
The sample was filled into graduated cylinder (250 mL) and its temperature was recorded. Hydrometer was used to measure the SG of the fuels specified (Figure 11). Then, temperature correction factors (according to tables from (ASTM D 1250-80, 1980; Petroleum Measurement Tables, 1963)) were applied to convert the measured specific gravities to the reference temperature of 60/60°F and densities were taken at temperatures of 15°C and 20°C.

3.2.5.5 Determination of Boiling Point Range (Distillation Characteristics Test) (ASTM D86)
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 12 & Plate 1). 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 (Eq 7) (ASTM D 1250-80, 1980).

Graduated Cylinder

Figure 11: Hydrometer for measuring specific gravity
Plate 1: Petroleum products distillation apparatus
(Photo author)

\[ Cc = 0.00012 \times (760P)(273+tc) \]  \hspace{1cm} (Eq. 7)

Where, \( tc \) = The observed temperature reading, \( ^oC \)

\( Cc \) = Corrections to be added algebraically to the observed temperature readings.

\( P \) = Barometric pressure, prevailing at the time and location of the test, mmHg.

Thence, Corrected temperature (\( ^oC \)) = \( tc + Cc \)

3.2.5.6 Determination of Cetane Number (CN)

Determinations using empirical formulas (Kalayasiri et al., 1996)

Using the results for Saponification number (SN) and Iodine value (IV) of oils, the CN was calculated with the help of (Eq 8 (a))

\[ CN = 46.3 + \frac{5458}{SN} - 0.225 \times IV \]  \hspace{1cm} (Eq. 8a)

While, cetane number index (CNI) of No.2 diesel was calculated using corrected mid boiling point value from (Eq. 8b) ASTM (D 976).

Figure 12: The petroleum products distillation layout

\[ \text{Cetane Index} = 454.74 - 1641.416D + 774.74D^2 - 0.554B + 97.803(\log B)^2 \]  \hspace{1cm} (Eq. 8b)

Where, \( D \) = Density at 15 \( ^oC \), g/ml

\( B \) = Corrected mid boiling point \( ^oC \),

3.2.5.7 Determination Of Kinematic Viscosity (ASTM D 445).

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 mns to reach the equilibrium temperature of 40 oC. The time (t) was measured for a fixed volume of liquid to flow under gravity through the capillary of a calibrated viscometer (Figure 13 and Plate 2) and at a closely controlled and known temperature. The kinematic viscosity is then equal to the product of this time and a calibration constant for the tube (Eq 9) (ASTM 2002).

Plate 2: Cannon-Fenske glass capillary
Viscometer apparatus (Photo author)

Kinematic Viscosity = C X t ------------------------- --------------------------------------- (Eq. 9)

Where, C = calibration constant (mm$^2$/s) 

$\frac{t}{s}$

3.2.5.8 Determination of Calorific Value (CV) (Parr, 1987)
Calorific value (energy content or heat of combustion) of a fuel was determined by bomb calorimeter. Benzoic acid was used to standardize the calorimeter. One gram of sample was taken in a crucible and made into a pellet and the initial weight was noted. It was placed in the bomb, which is pressurized to 18 atm of oxygen. The bomb was placed in a vessel containing a measured quantity of water (2000g). The ignition circuit was connected and the water temperature noted. After ignition the temperature rise was noted every minute till a constant temperature was reached. The pressure was released and the length of unburned fuse wire was measured. And the determination of the biodiesel’s calorific value was conducted following the same procedure for standardization, except for the sample preparation, which were liquid.

The calorific value was calculated from (Eq 10): (Parr, 1987)
Where, $H_g =$ Gross heat of combustion
\[
t_c = \text{Temperature rise (°C)},
\]
\[
w = \text{Energy equivalent of calorimeter in Cal/°C},
\]
\[
m = \text{Mass of sample in grams}
\]
\[
e_1 = \text{Correction in calories for heat of formation of HNO}_3
\]
\[
e_2 = \text{Correction in calories for heat of formation of H}_2\text{SO}_4
\]
\[
e_3 = \text{Correction in calories for heat of combustion of fuse wire}
\]

3.2.5.9 Determination of Flash Point (FP)
The Pensky-Martens Closed Cup Tester was used (Figure 14 and Plate 3). 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 Hg =
Corrected FP = T (°C) + 0.033(760 - P) .................................................. (Eq. 11)

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

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

3.2.5.10 Determination of Cloud Point (CP) ASTM D 2500

The Peltier device (Figure 15 & Plate 4) was used to measure the CP. As described in ASTM D 2500, 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.
IV. RESULTS AND DISCUSSION

4.1 Oilseed Plants Assessed and Agroecological Requirements

The different oilseed crops as; R. communis, B. crinata, J. curcas and E. guineensis assessed were observed to require different agroecological conditions and soil types as presented in (Table 8) below.

Table 8: Survey results of agro-ecological requirements of studied Oil crops

<table>
<thead>
<tr>
<th>Agro-climatic requirements</th>
<th>No. Type of Oil Plant</th>
<th>Altitude range (masl)</th>
<th>Temperature range (°C)</th>
<th>Rainfall range (mm)</th>
<th>Soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 R. communis</td>
<td></td>
<td>1200-2000</td>
<td>20-26</td>
<td>400-900</td>
<td>Sandy loam, pH 5-6.5</td>
</tr>
<tr>
<td>2 B. carinata</td>
<td></td>
<td>2000-2600</td>
<td>(mean) 500-650</td>
<td>Any, gravelly, sandy and saline soils. It can thrive on the poorest stony soil and even in the crevices of rocks</td>
<td></td>
</tr>
<tr>
<td>3 J. curcas</td>
<td></td>
<td>0-1700 &gt;20 300-1000</td>
<td>Max 30-32 Min 21-24</td>
<td>Wide range of tropical soil, except water logged, pH 4-6</td>
<td></td>
</tr>
<tr>
<td>4 E. guineensis</td>
<td></td>
<td>0-1200 Max 30-32</td>
<td>2000</td>
<td>Data as discussed in section (2.5)</td>
<td></td>
</tr>
</tbody>
</table>

Data as discussed in section (2.5)
R. communis (castor) overwhelms all over the country, as self-propagating weed. However, the highest seed yield was obtained at lower altitudes (1200 – 2000 masl). The plant is highly resistant to moisture stress that well thrive in the areas of rainfall ranging between 400-900 mm. The soil requirement is sandy loam with pH of 5-6.5 (Table 8). Castor leaf is also used as a feed for silkworm for production of silk, as practiced at household level in rural areas (Plates 5, 6 & 7).

Plate 5: R. communis (castor) wild (Photo: author)  
Plate 6: Flower of R. communis (Photo: Dr Mekuria Tadesse)  
Plate 7: Additional uses of castor (silk production), Awassa (Photo: author)

Plate 5 Plate 6 Plate 7

There is 100 ha oil palm plantation (established since 1992) in the South western part of the country, Gambela Administrative region, Godere wereda, specific area known as Gelesha (636 Km form the capital). The plantation is under the supervision of Teppi Coffee Farm (branch of Coffee Plantation Development Enterprise) (Plates 8, 9 &10). The area has an altitudinal range of 930-980 masl and well known with its longest rainy season in the country.

Plate 8: Young oil palm (Photo: author)  
Plate 9: Oil palm plantation view (Teppi) (Photo: author)  
Plate 10: Harvesting the matured bunch of the oil palm (Photo: author)

However, the recorded data, from the Teppi Coffee Farm office, indicates that most of the product was underutilized, owing to lack of proper harvesting and processing techniques. Most of the matured fruit bunches deteriorate in the field uncollected. On the other hand, while the immature fruit is characterized with lower oil yield, over maturity results higher fatty acid proportion in the oil. Consequently, the product had been rejected (by the Quality and Standards Authority of Ethiopia) as food oil, due to its high free fatty acid content resulted from improper harvesting and extraction processes.

J. curcas was predominantly observed in the low land areas in altitudinal range of 0-1700 masl. The rural households plant it as a hedge for protection of other crops from animals, while others plant it in the farm plot as a demarcation line between two plots of different ownerships, or as a live fence around the residences (Plates 11, 12 & 13). The plant is highly resistant to moisture stress as it sheds its leaves during the dry season and flourish just as it gets little moisture and well thrive in the regions of average annual rainfall.
ranging between 300-1000 mm. *J. curcas* grow on any type of well-drained soil as; gravelly, sandy and saline soils. It can thrive on the poorest stony soil and even in the crevices of rocks. However, the uses of *jatropha*'s oil were not known anywhere in the country. There are some trial plots at Adami Tullu (by the Essential Oils Research Center) and at Melkasa Agricultural Research Center experimental sites.

Plate 11: *Jatropha* during the dry season (Photo: Dr Mekuria Tadesse)
Plate 12: *Jatropha* during the rainy season (Photo: Dr Mekuria Tadesse)
Plate 13: *Jatropha* seed collection from around farm plot (Photo: author)

*B. carinata* is widely cultivated in the high land and semi-highland parts of the country, while better yield was registered at an altitude ranging from 2000-2600 masl. In addition, it prefers low temperature (mean about 20°C) with average rainfall of 500 to 650 mm. It requires well-drained heavy type of sandy loam or a light clay soil, with soil acidity between pH 6 to 7.5. Researches conducted indicated that high lands of Shewa, Arsi, Bale, Gojjam, Awassa, Kokate, Hossina, Hagereselam, Waka and Bule are very suitable for the different varieties of the crop. Among the varieties released by the agricultural research centers *â€œYellow Dodolaâ€ was preferred for biodiesel test due to its higher yield and prevalence.

4.1.1 Delineation of the suitable areas for respective oil crops

Based on the aforementioned agroecological requirements, area suitability assessment was carried out and the country’s different agroecological zones were delineated using ArcGIS software and the spatial analyst tool (Figure 16) and these areas were related to each oil plant’s specific altitudinal requirements mentioned in (Table 8). It can be deduced that most part of the country is from hot-arid to warm semi-arid climate, with altitudes ranging between 0â€“1500 masl (the yellow and orange region) (Figure 16 a).
Figure 16: (a) The five traditional Agro-ecological Zones in general, data from (MoA, 2000), (Appendix: 7).

Fig 16 (b) Area Classified According to the Respective Altitudinal Requirements of the Oil plants

Figure 16(b) shows that the brown area (0-1200 masl) are suitable for both J. curcas and E. guineensis while the green area is suitable for both J. curcas and R. communis (1200 â€“ 1700 masl). R. communis additionally suited to the blue region (1700-2000 masl). B. carinata is limited to the higher altitude (2000-2600) the red region. Nonetheless, these area suitability should be coincided with the rainfall and temperature requirements (Appendices: 8 & 9), in which E. guineensis is restricted to areas with high average annual rainfall of 2000 mm, while B. carinata requires high altitude areas and relatively fertile soil.

4.2 Oil Extraction and Characteristics Tests

4.2.1 Oil and Moisture Contents

Oil and moisture contents of the seeds collected were determined in which, the oil content results for the five collections of R. communis ranged from 36.45-45.76 %w/w, while the moisture content observed were 4.81-8.06 %w/w. The five different collections of R. communis (four of them planted on the same plot and one from other location) were compared and the result showed significant variation. This result shows that R. communis-2 from Awassa resulted the highest oil yield, 45.76%w/w and 3 tons per ha. The oil yield of R. communis is lower than that reported by UNIDO (1974), i.e., 50 to 52 %w oil and 5 to 6 ton per ha in Brazil. On the other hand, Akpan et al. (2006) reported oil and moisture contents of 33.2 and 4.15 %w respectively (in Nigeria), lower than the present result.

Figure 17: (a) Oil & moisture contents

B. carinata (Yellow Dodola variety) rendered oil content of 47.62 %w/w and moisture content of 6.17%w/w. It is in agreement with that reported by MoA (2002), i.e., 44%w. J. curcas, investigated at three different conditions resulted oil contents ranging 0 to 10.
from 29.55-41.04 %w/w and moisture contents from 5.01-8.79 %w/w, it was in agreement with Subramanian et al. (2005) and Muhlbauer et al. (1998). The results were evaluated by comparing respective values (Figure 17 (a)). Amongst all oil plants observed, B. carinata rendered the highest oil content per a given mass of seed. The variation in both oil and moisture contents between the different samples was strongly significant (P<.05). The moisture contents of all the seeds were below 9 %w, and the relationship with their respective oil contents shown weak negative correlation as (P >.05) (Figure 17 (b)).

The oil content and moisture content values for E. guineensis were not determined by soxhlet extraction method since the already hydraulic press extracted oil, obtained from the Teppi Coffee Farm, was used for analysis. However, the oil contents of 45-55 %w/w from fruit and 50%w/w from palm kernel were reported.
4.2.2 The Fatty acid Compositions and Biodiesel Yield

4.2.2.1 Fatty acid Compositions

The major fatty acid compositions of B. carinata, J. curcas, R. communis and E. guineensis were determined, after transesterification, using gas chromatography analysis.

The data indicates that each of the oil species has distinct characteristic fatty acid compositions, which on the other hand impose critical impacts on the resulting biodiesel qualities. B. carinata is dominated with monounsaturated large molecule, erucic acid, (44.2 ± 0.75 %); while R. communis is composed with high proportion of ricinoleic acid (87.97 ± 0.87 %) that contribute to its highest viscosity. The dominant fatty acid in J. curcas was observed to be linoleic acid (47.1 ± 0.58 %) that rendered it lesser viscosity and reduced cloud point. The highest component of E. guineensis is the saturated palmitic acid (44.4 ± 0.09 %) and hence it is solid at room temperature. Therefore, the overall properties of the biodiesel are determined by the dominant fatty acids. Figure 18 compares the relative proportion of the fatty acids among the different oils (tabulated in Appendix 11). The results were in good agreement with the previous findings of (UNIDO, 1974; Bringi, 1987 and Darnoko and Cheryan, 2000).
B. carinata  R. communis  J. curcas  E. guineensis
Oil samples

<table>
<thead>
<tr>
<th>Carbon No. : No. of double bonds</th>
<th>50</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition 1</td>
<td>30.7</td>
<td>8.81</td>
<td>96.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition 2</td>
<td>41</td>
<td>5.01</td>
<td>100.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condition 3</td>
<td>29.6</td>
<td>6.06</td>
<td>94.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Oil content %w/w
Moisture content
%Biodiesel

Figure 18: Comparison of the dominant fatty acids of each oil

4.2.2.2 Biodiesel Yield
The biodiesel was synthesized using batch wise transesterification process. After washing three times with hot water the clear solution of biodiesel was measured. The biodiesel production yield (weight percent of the oil) of R. communis, B. carinata, J. curcas and E. guineensis were found to be 99, 96.16, 100.7 and 88.87% respectively (Figure 19). J. curcas, with the least % of free fatty acid (FFA) content, in its crude oil (0.983 Carbon No. : No. of double bonds
mgKOH/g), rendered the highest biodiesel yield (100.7 %), while E. guineensis with high free fatty acid (12.873 mgKOH/g) resulted the least (88.87 %). It was pretreated with acid catalyst before transesterification. Increase in %FFA resulted in significant reduction of biodiesel yield, due to relatively higher amount of soap formation and also consumes extra catalyst. Amongst the five collections of R. communis the one with highest oil content (labeled no.2) was treated for biodiesel yield and physicochemical properties.

Figure 19: Biodiesel yield

It has also been observed that seed harvesting and storage conditions have great influential impacts on oil and moisture contents of the seeds as well as on the biodiesel yield.

Figure 20: Oil & Moisture contents and Biodiesel yield variations due to harvesting and storage durations

80.00
85.00
90.00
95.00
100.00
105.00
211231
R. communis
B. carinata J. curcas E. guineensis
Type of oils
Samples of seeds of Jatropha were collected at three different stages (Plates 14, 15 & 16), namely, seed dried and stored for more than 6 months (condition-1) purchased from farmers, seeds collected (just after the seeds mature and the fleshy exocarp dries and turned brown (condition-2)), seeds collected when the pods are mixed green and yellow (condition-3); and all were extracted under the same condition rendering the results of 30.7, 41, 29.6 %w for oil contents and 8.81, 5.01, 6.06 %w for moisture contents respectively as shown in (Figure 20).

In this case, seeds collected in condition-2 and extracted with in 15 days resulted the highest oil yield and lowest moisture content. Contrary to this, as can be seen from (Figure 20), seeds stored for a longer period of time showed reduced oil content and increased moisture content while the not-well matured seed (Plate 16) showed reduction in both oil and moisture contents. The highest biodiesel yield was also observed from condition-2 (Plate 15). This situation is in agreement with Gunstone (1958) that lipid content and the fraction of unsaturated fatty acid increases with maturity, while carbohydrate decline as soon as fat develops.

Plate 14: Jatropha seed (Condition-1) (Photo: author)
Plate 15: Jatropha seed (Condition-2) (Photo: author)
Plate 16: Jatropha seed (Condition-3) (Photo: author)

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4.2.3 Physicochemical Properties

4.2.3.1 Saponification number, iodine value and peroxide value
Saponification number (SN), iodine value (IV) and peroxide value (PV) of B. carinata oil (BcOIL), J. curcas oil (JcOIL), R. communis oil (RcOIL) and E. guineensis oil (EgOIL) were determined and the results depicted in (Table 9) were observed.

Table 9: Analysis of SN, IV and PV
The four oils showed almost similar saponification number (191-193 mg /g) that indicates their similarity in average molecular weight. The saponification value reported by Akpan et al. (2006) for R. communis (175-187 mg /g) was lower than the present result. Whereas the iodine value varies significantly; i.e., 79.47 for E. guineensis oil to 95.8 g I 2 /100g for B. carinata oil, that clearly indicates the variation in the oilsâ€™ unsaturation. E. guineensis oil is more saturated than others while B. carinata consists of relatively more unsaturated fatty acids. Iodine value for J. curcas reported by Francis et al (2005) ranged from 95-106 g I 2 /100g, a bit higher than the present result. And the iodine value of 82-88 g I 2 /100g was reported for R. communis by UNIDO (1974) and Akpan et al. (2006) still higher than the present result. This may be due to higher proportion of unsaturated fatty acid compositions attribute of that geography, as stated by Gunstone (1958) that the altitudinal variation determines the proportion of unsaturation which increases with altitude. As reported by Graboski et al. (1999), unsaturation can impact emissions, as free radical scavenging may be impacted by the number of olefinic bonds present. Nevertheless, all the present oils showed acceptable iodine values, i.e., <120 g I 2 /100g, that agrees with EN standard specification (EN, 2003).

Response to query:

Sample SN mg of soap (as potassium oleate)/g of oil

<table>
<thead>
<tr>
<th>Oil</th>
<th>SN (mg/kg)</th>
<th>IV (g I 2)</th>
<th>PV (Meq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BcOIL</td>
<td>191.02 ± 0.3</td>
<td>95.8 ± 0.11</td>
<td>22.15 ± 0.76</td>
</tr>
<tr>
<td>JcOIL</td>
<td>191.27 ± 0.43</td>
<td>95.24 ± 0.43</td>
<td>10.79 ± 1.16</td>
</tr>
<tr>
<td>RcOIL</td>
<td>192.97 ± 0.66</td>
<td>81.6 ± 0.66</td>
<td>15.67 ± 0.12</td>
</tr>
<tr>
<td>EgOIL</td>
<td>192.07 ± 0.58</td>
<td>79.47 ± 0.57</td>
<td>6.09 ± 0.63</td>
</tr>
</tbody>
</table>

The Peroxide value ranges from 6.09 for E. guineensis oil to 22.15 Meq/kg of oil for B. carinata oil. The formation and increasing quantity of the peroxide value is a strong
indication for continuous deterioration of the oil. Peroxides are strong oxidizing agents (Martin and Harbinson, 1979). The peroxides and their oxidative products are also associated with the off-odors of some oils (Lavers, 1991)

4.2.3.2 The specific gravity
The specific gravity (SG) and density of the oils and their corresponding biodiesels (BD) of B. carinata, J. curcas, R. communis and E. guineensis were determined. Reduction of specific gravity and density, after transesterification, was observed, except for E. guineensis which showed increment, as depicted in (Figure 21). This might be due to high proportion of free fatty acid that floated to the surface during sampling, as glycerol, monoglyceride and diglyceride sink to the bottom. The results showed densities of B. carinata and J. curcas were in agreement with the EN standard specification for density of biodiesel, i.e., (0.860-0.900 g/mL) while those of R. communis and E. guineensis were beyond the limit. The specific gravity and density of conventional No. 2 diesel fuel is 0.84 and 0.8395 respectively, indicating that the density of biodiesels is greater than conventional diesel fuel. There is significant variation in densities among the biodiesels from the different oils (P<.05). According to Clark (1988), low relative density is indicator of good ignition properties of fuels.

Figure 21: Comparison of densities of oils and their corresponding BDs Vs No.2 Diesel

<table>
<thead>
<tr>
<th>Density @ 15 °C (g/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.82</td>
</tr>
<tr>
<td>0.84</td>
</tr>
<tr>
<td>0.86</td>
</tr>
<tr>
<td>0.88</td>
</tr>
<tr>
<td>0.9</td>
</tr>
<tr>
<td>0.92</td>
</tr>
</tbody>
</table>

BcOIL = Brassica carinata oil  BcME = Brassica carinata methyl ester
JcOIL = Jatropha curcas oil  JcME = Jatropha curcas methyl ester
RcOIL = Ricinus communis oil  RcME = Ricinus communis methyl ester
EgOIL = Elaeis guineensis oil  EgME = Elaeis guineensis methyl ester
4.2.3.3 The kinematic viscosity

The kinematic viscosity (KV) measured for the oils and biodiesels of B. carinata, J. curcas, R. communis and E. guineensis was found to be 29.21, 19.74, 161.35 and 40.07 for the oils and 5.09, 3.75, 10.94 and 13.91 mm²/s for biodiesels respectively, as shown in (Figure 22). Significant reduction in KV were observed after transesterification. The result obtained for B. carinata and J. curcas Biodiesels were within the limit of ASTM and EU specification (1.9 -6 mm²/s), while those of R. communis and E. guineensis (10.94 and 13.91 mm²/s) respectively, though reduced after transesterification, were far beyond the maximum limit. This indicates that biodiesels, in general, are more viscous than No. 2 diesel fuel (3.5 mm²/s), and that the biodiesels' viscosity vary depending on the type of seed oil that also depends on fatty acid composition and level of unsaturation of the respective oils. The higher viscosity of R. communis is attribute of its high proportion of hydroxyacid (ricinoleic acid), while that of E. guineensis is due to the higher proportion of saturated palmitic acid. Amongst all, J. curcas resulted the least viscosity (3.75 mm²/s), that shows its perfect performance in engines similar to conventional diesel (Figure 22). All the biodiesels showed significant difference in viscosity (P <.05).

Higher viscosities have impact on fuel pump and injector operation resulting poorer atomization of the fuel spray and has been associated with increased engine deposits.
Figure 22: Comparison of Kinematic Viscosities of Oils and their corresponding Biodiesels Vs Diesel

BcOIL = Brassica carinata oil  BcME = Brassica carinata methyl ester
JcOIL = Jatropha curcas oil  JcME = Jatropha curcas methyl ester
RcOIL = Ricinus communis oil  RcME = Ricinus communis methyl ester
EgOIL = Elaeis guineensis oil  EgME = Elaeis guineensis methyl ester

Kinematic Viscosity mm²/s:

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>BcOIL</th>
<th>BcME</th>
<th>JcOIL</th>
<th>JcME</th>
<th>RcOIL</th>
<th>RcME</th>
<th>EgOIL</th>
<th>EgME</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>2.00</td>
<td>1.00</td>
<td>3.00</td>
<td>2.00</td>
<td>4.00</td>
<td>2.00</td>
<td>6.00</td>
<td>5.00</td>
</tr>
<tr>
<td>20</td>
<td>2.00</td>
<td>1.00</td>
<td>3.00</td>
<td>2.00</td>
<td>4.00</td>
<td>2.00</td>
<td>6.00</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Blends of BDs:

<table>
<thead>
<tr>
<th>Blend</th>
<th>Viscosity (mm²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eg5Bc95ME</td>
<td>2.00</td>
</tr>
<tr>
<td>Eg10Bc90ME</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Eg20Bc80ME  
Eg50Bc50ME  
Rc10Bc90ME  
Rc10Jc90ME  
Diesel

The kinematic viscosities of the blends of E. guineensis with B. carinata from 5 to 50% showed increment with the proportion of E. guineensis, indicating that up to 20% the viscosity falls in the limit of specification for biodiesel. Similarly, the 10% R. communis with B. carinata resulted 4.64 mm$^2$/s which is within the limit of ASTM and EN specifications, as depicted in (Figure 23).

Figure 23: Variation of KV with Blends

4.2.3.4 Calorific Value

Calorific Value or gross heat content (Hg) of the biodiesels of B. carinata, J. curcas, R. communis and E. guineensis were determined to be 39.31, 38.71, 36.86 and 38.95 MJ/Kg respectively as depicted in (Table 10). The heat value result reported by Graboski et al. (1999) was 40.39 and 40.37 MJ/Kg for methyl rape and methyl soy respectively. While that reported by Van Jerpen et al. (2004) was 37.21 MJ/Kg for methyl soy. The present result ranged between the results of these two authors.

Eg5Bc95ME = 5% E. guineensis + 95% B. carinata  
Eg10Bc90ME = 10% E. guineensis + 90% B. carinata
Eg20Bc80ME = 20%  E. guineensis + 80% B. carinata
Eg50Bc50ME = 50%  E. guineensis + 50% B. carinata
Rc10Bc90ME = 10%  R. communis + 90% B. carinata
Rc10Jc90ME = 10%  R. communis + 90% J. curcas

56

Table 10: Gross Heating Value (Hg) of the biodiesels

The energy content for the No.2 diesel showed higher value than the biodiesels tested (42.7 MJ/Kg). The heat value difference with respect to each biodiesel was analyzed as depicted in (Table 10). Consequently, comparison of the calorific values of the biodiesels Vs. the No.2 diesel indicated that the biodiesels are 7.49 to 13.67 % less energy content than diesel. The more the proportion of oxygen the lower energy content.

4.2.3.5 Cetane number

Cetane numbers of B. carinata, J. curcas, R. communis and E. guineensis were calculated from (Eq 8-a) using the data for saponification numbers and iodine values. The results ranging from 53.32 to 56.83 were obtained as depicted in (Table 12), with E. guineensis methyl ester showing the highest value. The cetane number index (CNI) of No.2 diesel (No.2D) was calculated using corrected mid boiling point value from (Eq 8-b). The cetane number results are in agreement with the standard specifications of both ASTM and EN, i.e., >47 and >51 respectively. There is significant variation between the samples (P<.05). Cetane number values reported by Graboski et al. (1999) were 47.2 and 55.7 for soy methyl ester and canola methyl ester respectively, that indicates the lower cetane number of soy methyl ester is attributable to its more unsaturated fatty acid components.

Table 11: Calculated Cetane Numbers (CN)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Hg (MJ/Kg)</th>
<th>% Difference (MJ/Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BcME</td>
<td>39.31 ± 0.722</td>
<td>-</td>
</tr>
<tr>
<td>JcME</td>
<td>38.71 ± 0.252</td>
<td>-7.94</td>
</tr>
</tbody>
</table>

BcME = Brassica carinata methyl ester
JcME = Jatropha curcas methyl ester
RcME = Ricinus communis methyl ester
EgME = Elaeis guineensis methyl ester
RcME 36.86 ± 0.145 -9.34
EgME 38.95 ± 0.212 -13.67
No.2D 42.70 -8.77
Sample BcME JcME RcME EgME No.2D
CN 53.32 53.41 56.24 56.83 53.82

4.2.3.6 The Flash Points (FP)
The Flash Points (FP) of the biodiesels were determined according to the standard procedure for measuring the flash point of biodiesel fuels, i.e., ASTM D 93. The observed FP of the properly washed biodiesels, i.e., methanol free biodiesels of B. carinata, J. curcas, R. communis and E. guineensis ranged from 94.78 to 193.78 °C (corrected temperature at 760 mmHg (Figure 24). All resulted higher flash points than petrodiesel (69.7 °C).

Figure 24: Comparison of Flash Point (FPs) of Biodiesels & Diesel

The result indicated that these biodiesels are non-inflammable and safer for handling. Whereas, the improperly washed biodiesel resulted flash point at 21.78 °C (Figure 24), due to the presence of residual methanol, implying that improper washing of biodiesel results risk of fire even below room temperature. The minimum flash point requirement is 120 °C (according to ASTM) and 130 °C (according to EN) standards.

Plats (17, 18 & 19) show biodiesel purification and pure biodiesel.

Plate 17: Phase separation of Biodiesel & glycerol (Photo: author)
Plate 18: Biodiesel washing, (catalyst & the soap at the bottom) (Photo: author)
Plate 19: Clear Biodiesel (Photo: author)

BcME = Brassica carinata methyl ester
JeME = Jatropha curcas methyl ester
RcME = Ricinus communis methyl ester
EgME = Elaeis guineensis methyl ester
Corrected FP (°C @760mmHg)

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
<td>125</td>
<td>150</td>
</tr>
<tr>
<td>175</td>
<td>200</td>
<td>225</td>
<td>BD &amp; Diesel</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Corrected FP (°C @760mmHg) 21.775 193.775 119.775 94.775 179.841 69.742
BcME* BcME JeME RcME EgME Diesel

* Improperly washed

Plate 17 Plate 18 Plate 19

58
4.2.3.7 The distillation characteristics
The distillation characteristics of B. carinata, J. curcas, R. communis and E. guineensis were determined. The initial boiling points (IBP) of 246, 323, 297 and 264 °C were recorded respectively. While the respective distillation values showed 80, 90, 90 and 60 % recovery, the final boiling point (FBP) ranges of 345 to 381 °C were recorded. All the biodiesels showed narrow ranges of distillation points (Figure 25), implying the characteristics of biodiesels having limited composition contrary to that of conventional diesel which have multiple components with varying boiling points. No2 diesel showed IBP at 188.55 °C, FBP at 370 °C and 90 % recovery at 351 °C. Biodiesels with lower percentage distillation recovery (less volatility characteristics) may be related to the
increased formation of coke, and unburned biodiesel.

Figure 25: Comparison of Distillation Range

While using simple distillation (accustomed for distillation of petroleum products), the biodiesels of B. carinata, J. curcas, R. communis and E. guineensis decomposed (cracked) at atmospheric pressure; giving smoky fume just above 381, 357, 348 and 345 o C; only at the recovery of 80, 90, 90 and 60 v% respectively. This shows the distillation tests following ASTM D 86 were not appropriate for biodiesel since the boiling temperatures of the compounds in biodiesel are so high at atmospheric pressure. Therefore, ASTM D 1160, which is conducted under vacuum, should be used.

BcME = Brassica carinata methyl ester
JeME = Jatropha curcas methyl ester
RcME = Ricinus communis methyl ester
EgME = Elaeis guineensis methyl ester
BP Range
0
50
100
150
200
250
300
350
400
450
IBP101520253040506075809095FBP
V%
Te
m
p
4.2.3.8 The cloud point
The cloud point (CP) is the temperature at which a cloud of wax crystals first appears in a liquid upon cooling was determined for B. carinata, J. curcas, R. communis and E. guineensis biodiesels. The results of 5, 0, -12 and 20 \degree C were recorded respectively as shown in (Figure 26). Oils with more saturated fatty acid composition rendered higher cloud point. As it is a measure of the low temperature performance of diesel/biodiesel fuels, the present result points the necessities of precaution while using biodiesel fuels, especially during the cool seasons. For instance, E. guineensis biodiesel may not be used in the highlands of Ethiopia where diurnal temperature is below 20 \degree C. However, it is of no such significance impact in warm tropical climates. Bol (2004) reported the cloud point results of refined soyethylester and unrefined soyethylester to be -9 and 15 \degree C, that indicates refined oils result lower cloud points.

Cloud Point
5 0 -12 20 -2 6 4 13 5 -1 -16 -12 -8 -4 0 4 8 12 16 20
Sample Temp C

Figure 26: Comparison of Cloud Points of the Biodiesels and the Blends

The blending of the biodiesels on the other hand, resulted lower cloud point up to -1 o C as shown in (Figure 26). Cloud point is not specified on the standards. It is determined by local climate such that, it should be below the monthly tenth percentile minimum ambient temperature for the region (ASTM 1, 2002).

Eg5Bc95ME = 5% E. guineensis + 95% B. carinata
Eg10Bc90ME = 10% E. guineensis + 90% B. carinata
Eg20Bc80ME = 20% E. guineensis + 80% B. carinata
Rc10Bc90ME = 10% R. communis + 90% B. carinata
Rc10Jc90ME = 10% R. communis + 90% J. curcas

4.2.3.9 Acid values
Acid values of B. carinata, J. curcas, R. communis and E. guineensis Biodiesels were determined resulting; 0.885, 0.338, 0.566 and 1.802 mgKOH/g respectively (Figure 27). The results indicated that the acid values of the oils decreased significantly after transesterification. J. curcas and R. communis biodiesels resulted acid values within the standard specification limit (max 0.8, ASTM D 664). The acid value of E. guineensis, even though decreased form 12.87 to 1.8 mgKOH/g after transesterification, still showed the highest value due to the tendency of the methyl ester of the oil to hydrolyze rendering more free fatty acids. Higher acid value resulted low yield of biodiesel. Ajiwe et al. (2003) reported acid value result of 2.72 mg/g for palm oil ester that is rather higher than the present result.
mgKOH/g
Types of Oils & BDs
Acid Value
Series1 1.661 0.885 0.983 0.338 0.566 12.873 1.802
BcOIL BcME JcOIL JcME RcOIL RcME EgOIL EgME

Figure 27: Comparison of Acid Values of the Oils and their corresponding Biodiesels

BcOIL = Brassica carinata oil  BcME = Brassica carinata methyl ester
JcOIL = Jatropha curcas oil  JcME = Jatropha curcas methyl ester
RcOIL = Ricinus communis oil  RcME = Ricinus communis methyl ester
EgOIL = Elaeis guineensis oil  EgME = Elaeis guineensis methyl ester

In summary, the physicochemical characteristics of the biodiesels, namely; Density @15°C, Kinematic Viscosity @40°C, Flashpoint, Cloud Point, Cetane No., Acid No. and Iodine Value were summarized and analyzed in comparison with the standards as depicted in (Table 13). It is clearly observed that, J. curcas compromise with all the standard specifications of ASTM D 6751 and EN 14214, except for flash point result of 120 °C, i.e., less than the EN 14214 specification (min 130 °C).

B. carinata meets both standards, except in acid No. result of 0.885 mgKOH/g, which exceeded both limitations, and kinemate viscosity result of 5.09 mm²/s exceeding the range set by EN 14214 of (3.5-5.0 mm²/s). R. communis fails to meet both the standards in density (0.9269 g/mL), kinematic viscosity (10.94 mm²/s) and flashpoint (95 °C) and that of EN in acid No. (0.566 mgKOH/g) while E. guineensis fails to meet both the standards in density (0.9121 g/mL), kinematic viscosity (13.91 mm²/s) and acid No. (1.802 mgKOH/g). Moreover, E. guineensis solidifies at higher temperature, as it resulted cloud point at 20 °C while R. communis didn’t show cloud point even at -12 °C, indicating its performance at lower temperature areas.
Table 12: Summary of the physicochemical characteristics (mean values) of biodiesels in comparison with the standards of ASTM and EN

<table>
<thead>
<tr>
<th>Type of Biodiesel</th>
<th>Fuel properties</th>
<th>Specifications</th>
</tr>
</thead>
</table>
|                   | Unit BcME RcME JcME EgME No.2 diesel US ASTM D6751 EN 14214 | Density @15° C g/mL 0.8731 0.9269 0.8779 0.9121 0.8395 *** 0.86-0.9 Kinematic Viscosity @40° C mm 2 /s 5.09 10.94 3.75 13.91 3.5 1.9-6.0 3.5-5.0 Distillation @95% °C *** *** max360 **** Flashpoint °C 194 95 120 180 69.74 min 120 Min 130 Cloud Point °C 5 -12 0 20 -2 **** **** Cetane No. - 53.32 56.24 53.41 56.83 53.82 min 47 min 51 Acid No. mgKOH/g 0.885 0.566 0.338 1.802 ** max 0.8 max 0.5 Iodine Value gI 2 /100g 95.8 81.6 95.24 79.47 ** **** max 120 * Distillation @95% not reached (by simple distillation) ** Not determined *** No standard in ASTM **** No standard in EN 4.2.4 The effect of blending on some dominant fatty acids and physicochemical characteristics

Blends of the biodiesels at different proportions, namely; methyl esters of Bc100, Eg5Bc95, Eg10Bc90, Eg20Bc80, Eg50Bc50 and Eg100 were tested on GC for the changes in trends of fatty acid compositions. The result showed clear proportional changes depending on the dominant fatty acids. The high erucic acid in B. carinata decreased while the percentage of palmitic and oleic acids increased with proportions of E. guineensis (Figure 28).

These compositional changes have showed direct impact on the physicochemical characteristics of the biodiesels. The test conducted on viscosities and cloud points showed that, blends of different proportions of the biodiesels rendered promising results that compromise with the standards. Blend of 5-50% E. guineensis and 95-50% B. carinata resulted viscosity of 4.7-6.9 mm 2 /s (Figure 29), while that of 10% R.
Blends

Kine

ematic viscosity (mm²/s)

communis and 90% J.curcas rendered viscosity and cloud point of 4.67 mm²/s and -10°C respectively.

Figure 28: The effect of blending on some dominant fatty acids composition
It can also be generalized, from the results, that some properties have significant correlations with each other. For instance, iodine value increases as the number of double bonds increase but inversely proportional with viscosity, cetane number and

- Eg5Bc95ME = 5% E. guineensis + 95% B. carinata
- Eg10Bc90ME = 10% E. guineensis + 90% B. carinata
- Eg20Bc80ME = 20% E. guineensis + 80% B. carinata
- Eg50Bc50ME = 50% E. guineensis + 50% B. carinata
- Rc10Bc90ME = 10% R. communis + 90% B. carinata
- Rc10Je90ME = 10% R. communis + 90% J. curcas
- Bc100 = 100% B. carinata
- Eg 100 = 100% E. guineensis

0 5 10 15 20 25 30 35 40 45 50
Biodiesel blends
w%
Palmitic (16:0)
Stearic (18:0)
Oleic (18:1)
Linolenic (18:3)
Arachidic (20:0)
Arachideic (20:1)
Erucic (22:1)

63
0
50
100
150
200
250
300

Palmitic (16:0)
Stearic (18:0)
Oleic (18:1)
Linolenic (18:3)
Arachidic (20:0)
Arachideic (20:1)
Erucic (22:1)
Figure 30(a, b, c & d) show the impacts of the type of fatty acids on some biodiesel properties. However, R. communis rendered extraordinary characteristics which deviate from this generalization, in which it showed highest viscosity but lower iodine value and lower calorific value. This is due to the dominance of almost one type of hydroxyl fatty acid (ricinoleic acid).
Figure 30: (a) The relationships of iodine value ((IV) gI₂/100g), viscosity (mm²/s) and cetane number (CN) values for pure fatty acids (from Appendix: 1).

Figure 30 (b) The Relationships of Iodine value, Viscosity and Cetane Number values in this work
The linear regression analysis confirmed the existence of strong correlations between viscosity & iodine value and cetane number & iodine value (P<.05). (Figures 30 c& d).
Iodine value g (I2/100g)
Cetane number
Viscosity mm2/s
Calorific value (Mj/Kg)

Figure 30(c) Linear Regression for Viscosity vs Iodine value
10
12
14
R = -0.97806
Viscosity (mm²/s)
Iodine value (gI₂/100g)

Figure 30 (d) Linear Regression for Cetane number vs Iodine value
Y = 56.02561 - 0.54078X
R = -0.97806
P = 0.02194
Y = 73.62626 - 0.21216
R = -0.99951
P = 0.000490765

4.3 Feasibility analysis

Employing the results of oil & biodiesel yield and using the current petrodiesel consumption of the country, as a basis, the total amount of oilseed needed, land requirement for cultivation of the seed as well as input and output required in the process of biodiesel production were deduced as depicted into (Tables 14 & 15).

Table 13: Biodiesel and land requirement to substitute diesel consumption of the country

From the results of the biodiesel synthesis it can be calculated that B. carinata, J. curcas, R. communis and Elaeis guineensis resulted 1.38, 2.05, 1.41 and 4.4 tons of biodiesel per ha. Using their respective energy contents of 39.31, 38.71, 36.86, and 39.95
<table>
<thead>
<tr>
<th>Type of Oil Seed</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. carinata</td>
<td>J. curcas</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average seed yield Kg/ha</th>
<th>3000</th>
<th>5000</th>
<th>3100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average oil yield (w%)</td>
<td>48</td>
<td>41</td>
<td>46</td>
</tr>
<tr>
<td>Average oil yield Kg/ha</td>
<td>1440</td>
<td>2050</td>
<td>1426</td>
</tr>
<tr>
<td>Biodiesel yield w%</td>
<td>96</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td>Biodiesel (T) per ha</td>
<td>1.38</td>
<td>2.05</td>
<td>1.41</td>
</tr>
<tr>
<td>Heating value of BD (GJ/T)</td>
<td>39.31</td>
<td>38.71</td>
<td>36.86</td>
</tr>
<tr>
<td>Total heating value of biodiesel GJ per ha</td>
<td>54.34</td>
<td>79.36</td>
<td>52.04</td>
</tr>
<tr>
<td>Annual petro-diesel consumption of Ethiopia (T) 2006/7</td>
<td>905,477.80 905,477.80 905,477.80 905,477.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating value of diesel (GJ/ton)</td>
<td>42.7</td>
<td>42.7</td>
<td>42.7</td>
</tr>
<tr>
<td>Total Energy required (GJ)</td>
<td>38663902.06 38663902.06 38663902.06 38754449.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Biodiesel requirement (T) for 100% replacement</td>
<td>983564.03 998809.15 1048939.29 994979.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biodiesel (T)</td>
<td>49178.20</td>
<td>49940.46</td>
<td>52446.96</td>
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<tr>
<td>For 5% replacement</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Land requirement (ha)</td>
<td>35636.38</td>
<td>24361.20</td>
<td>37196.43</td>
</tr>
<tr>
<td>Biodiesel (T)</td>
<td>98356.40</td>
<td>99880.91</td>
<td>104893.93</td>
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<tr>
<td>For 10% replacement</td>
<td>**</td>
<td>**</td>
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<tr>
<td>Land requirement (ha)</td>
<td>71272.76</td>
<td>48722.40</td>
<td>74392.86</td>
</tr>
<tr>
<td>Biodiesel (Ton)</td>
<td>196712.81</td>
<td>199761.83</td>
<td>209787.86</td>
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<tr>
<td>For 20% replacement</td>
<td>**</td>
<td>**</td>
<td>**</td>
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<tr>
<td>Land requirement (ha)</td>
<td>142545.51</td>
<td>97444.79</td>
<td>148785.71</td>
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<tr>
<td>Biodiesel (T)</td>
<td>491782.02</td>
<td>499404.57</td>
<td>524469.64</td>
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<tr>
<td>For 50% replacement</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Land requirement (ha)</td>
<td>356363.78</td>
<td>243611.99</td>
<td>371964.29</td>
</tr>
<tr>
<td>Biodiesel (T)</td>
<td>786851.22</td>
<td>799047.32</td>
<td>839151.43</td>
</tr>
<tr>
<td>For 80% replacement</td>
<td>**</td>
<td>**</td>
<td>**</td>
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</table>
570182.05 389779.18 595142.86 180905.36
Biodiesel (T)
983564.03 998809.15 1048939.29 994979.46
For 100% replacement
Land requirement
(1)
712727.56 487223.97 743928.57 226131.69
Total present crop area of the country
(1) 11292572 11292572 11292572 11292572
% of land required for 100% Biodiesel
substitution (present crop area) 6.31 4.31 6.59 2.00

66
GJ/ton and relating the values obtained to the energy content of 42.7 GJ/ton of No.2
diesel, and the total annual petro-diesel consumption of Ethiopia (905,477.8 Ton (EPE,
2006/07)), total amount of Biodiesel and corresponding land required per annum
were computed to be 0.98, 0.99, 1.05 and 0.99 million tons and 0.71, 0.49, 0.74, and
0.22 million ha respectively (Table 14).

As shown in (Table 14), the land requirement for jatropha, to substitute 100% of the
current diesel consumption, is only 4.31% of the present total crop area of the country
(11,292,572 ha) (CSA, 2007). It is equivalent to the area (1m X 400m) required by the
live fence around cropland per one ha.

Every biodiesel production unit on average produces about 12.5 % of glycerin and 2.3
% of fertilizer (Table 15). The byproducts, glycerin and cake, are valuable products
which further reduce the cost of Biodiesel. In addition, oil cake; can be used as a raw
material for production of fertilizer, animal feed or biogas, which could trigger the start
of many type of industries. The table clearly shows that, to produce the required
998,809.14 tonnes of biodiesel from J. curcas, 124,851.14 tons of glycerin, 22,972.61
tons of potassium phosphate fertilizer and 1,315,504.73 tons of oil cake will be
obtained.

Table 14: Inputs Required & Resulting Outputs

---

Based on the findings by Gasol et al. (2007) that production of B. carinata for energy
contribute to emission reduction by up to 5.2 g CO
2
eq. per MJ. Hence, replacement of
Input/Output Input required
Input streams:
Unit
Per
100 T
oil
B. carinata R. communis J. curcas E. guineensis
Oilseed T 2134470.55 2303336.17 2436119.88
Mass of refined oil T 1024545.86 1059534.63 998809.15 1130657.33
Primary alcohol (Ethanol) T 10.7 109626.41 113370.21 106872.58 120980.46
Catalyst (KOH) T 0.35-1 3585.91 3708.37 3495.83 11306.58
Neutralizer (Phosphoric acid) T 0.8 8196.37 8476.28 7990.47 9045.27
Water T 1.7 17417.28 18012.09 16979.76 19221.19
Electricity 1000 kWh 2 20490.92 21190.69 19976.18 22613.17
Output streams:
Biodiesel T 88-100 983564.03 1048939.28 998809.14 994979.45
Glycerin T 12.5 128068.23 132441.83 124851.14 141332.31
Fertilizer T 2.3 23564.55 24369.30 22972.61 26005.14
Oil cake T 1024545.865 1153715.488 1315504.73 1130658.474

38,663,902.06 GJ of fossil energy will reduce 201,052 T of CO
2
67
eq, and more for perennial oil crops that require less or no fertilizers. The biodiesel production cost was estimated to be 0.43 â€“ 0.39 USD (by the Planning Commission, of Government of India, as cited in Subramanian et al. (2005)). It is equivalent to 3.9 - 3.6 ETB, which is much cheaper when compared to the diesel price of 6.9 ETB at Addis Ababa. However, Coltrain (2002) indicated that the cost of biodiesel was higher than that of petroleum diesel, as biodiesel costs 1.4-2.4 USD per gallon compared to 1.0 â€“ 1.5 USD per gallon for petroleum diesel. This was due to its being produced mostly from expensive high quality virgin oil. Therefore, use of low cost feedstock should help biodiesel competitive in price with petroleum.

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V. CONCLUSION AND RECOMMENDATIONS
5.1 Conclusion
The various agroecological zones of the country were found to be ideal for cultivation
of different species of the oil-bearing plants. The hot-arid and warm semi-arid regions (0-1200 masl) cover the wider land mass of the country (Somali, Eastern Oromiya, SNNP, Gambela, Afar, Benishangul Gumuz, N-Western Amahara and N-Western Tigray regions). These areas were found to be most suitable for cultivation of important oil crops as; J. curcas, and E. guineensis simultaneously (provided that the RF requirement is attained); and the altitude between (1200-1700 masl) is favorable in common for J. curcas and R. communis (E & W-Oromiya, N-SNNPR, E & W Tigray & Amhara, N-Somali), while the area (1700-2000 masl) is suitable for R. communis only (most parts of Oromiya & Amhara). B. carinata is adapted to higher altitudes, between 2000 â€“ 2600 masl (Oromiya, Amhara & Tigray regions). Therefore, added to the relative cheap labor, using such opportunities will make the country the most beneficial in the soaring market of biodiesel, in many perspectives as, petroleum import substitution, fuel price stabilization, generating millions of jobs and stimulating enormous growth of rural incomes and ultimate national economic growth. In addition, planting perennial oil crops renders great ecological advantages in terms of erosion control and wasteland reclamation.

The present study further disclosed that, each of the oil plant species investigated is characterized with unique properties, that differ also depending on different geographical locations, as seed and oil yield per ha, biodiesel yield per ha, energy content GJ per ton and above all, with respect to the fuelâ€™s physicochemical characteristics to meet the standard specifications. These properties also depend on the agroclimatic conditions that indirectly influence economical viabilities and total land requirement to substitute the countryâ€™s current demand for No.2 diesel. In this respect, biodiesel yield per ha, energy content and the resulting fuel properties were considered as the most important limiting factors for reliable biodiesel production. The result shows strict preference of area suitable respective to oil crops, before biodiesel production commencement.

Amongst the oil plants investigated, J. curcas surpassed others in every aspect that rendered it a potential candidate as a best suitable substitute for diesel, seconding B. carinata. While the blends up to 20 % of R. communis and E. guineensis with J. curcas or B. carinata are essential in order to achieve the final desired properties of the fuel.

This is in line with the fact that, high level of linoleic and linolenic acid improve the cold flow behavior of the biodiesel, provided that it is suitably used in blend with one or more oils having lower linoleic and linolenic acid or higher palmitic or oleic acid levels in order to respect the standard specifications. Moreover, as the ambient temperatures, at different localities in the country, are generally higher than the cloud points detected for each biodiesel (except for E. guineensis which formed cloud at 20°C), they can be used without rendering problems of cold flow.

All the oil plants investigated were not listed among the invasive plants, they are not weeds and are not self-propagating (except R. communis), but has to be planted. They do not threaten food crops. J. curcas and R. communis could be used in stabilization of soils, erosion control, reclamation of arid and semi-arid lands and as hedge for control of livestock from other crops.

Moreover, biodiesel from these plant oils can be produced economically across a variety of places and scales; from urban to rural, small to commercial. The ease of manufacture
also contributes to biodiesel’s high net energy balance. On the other hand, it realizes the effort of distributed energy production, that means, using local resources - farmers can produce all the energy they need from what they grow on their own farms (by letting aside less than one-tenth of their cropping area to oilseeds). Especially jatropha is the best option to make biodiesel, because it is perennial, easier to plant and costs less.

5.2 Recommendations

Owing to the fact that, the average agricultural land holding per capita at present is 1.2 ha, and is inevitably diminishing as population continually grows, the existing agricultural land is clearly insufficient to be used for oil crops cultivation meant for biodiesel production, however little it requires. In this respect, the potential solutions for producing the cheapest vegetable oils for biodiesel in Ethiopia will be achieved through identification of diverse alternative non-edible oil crops and the usage of such crops where food crop production is low, degraded wastelands and at different parts of the country. This on the other hand, can avert the ecological problems of mono cropping which may pose severe biodiversity damage in the long run. Moreover, perennial oil crops are the most advantageous ones as they reduce costs of yearly plantation & fertilizers and used for erosion control.

Even though there is excess wasteland and/or degraded land available in Ethiopia, it has been realized that, since the recent data regarding land-use/land-cover (LU/LC) of the country is lacking, it is difficult to exactly delineate the required wasteland area for biofuel crop plantations. Therefore, detail studies of (LU/LC), especially pertinent to biodiversity, forest lands, protected areas, parks, agricultural lands etc. are highly recommended for efficient land management and to initiate sustainable biofuel production.

It is worthy mentioning that, the development of biomass energy will inevitably impose direct impact on biodiversity. Therefore, serious consideration of landscape-scale effects, the geographical locations, scale of development and spatial distribution of these crops are strongly recommended, to safeguard biodiversity rich habitats. Local, national, and regional policies and regulations should be enacted to ensure that impacts on wildlife, natural forest and soil quality are minimized.

To obtain economic cost data for performing the economic feasibility studies, conducting the mass and energy balance analysis of the full process is required. Besides, since the production areas and consumers for biodiesel may not be at the same place, distance of plantation areas is the main factor affecting the cost. In addition, the various process engineering principles should be utilized to collect the production data by analyzing the biodiesel production process in terms of the various inputs, outputs and their compositions. Such information is, in turn, needed for quantifying utility requirements and sizing equipment.

Detail studies regarding agronomic and environmental requirements are essential for feasibility analysis of both jatropha and oil palm (already existing 100 ha) in Ethiopia. The oil should be refined, bleached and deodorized at the plantation site, immediately after harvesting, and properly sealed and stored under strict control from contact with air. Since acidity increases with time, and higher acid value decreases the biodiesel yield and also damages the piping in a car's engine, which will lead to more costs;
therefore it should be pre-treated at the site before transesterification to bring it below the specification value.

Species improvement through organized selection and breeding programs, improving oil extraction technology, maximization of biodiesel production efficiency, raising the quality of by-products and developing the techniques of their conversion into useful products are the major issues requiring further investigations. Biodiesel R & D activities should be established to strengthen the biodiesel development in Ethiopia.

For local production of biodiesels, since residual alcohol (methanol or ethanol) and catalyst (usually KOH or NaOH) from the transesterification reaction can contaminate the final biodiesel product, proper washing and flash point tests at the spot of production are highly recommended to avert the hazards of unexpected fire.

Using the availability of various seed oils with distinct composition and physico-chemical characteristics as advantage, it is recommended to plan on the implementation of the blends of biodiesels from different types of vegetable oils in variable ratios; in order to achieve the final desired properties of the fuel.

From among the alcohols required for transesterification, ethanol is the most recommended for cost reduction in Ethiopia, since it is produced cheaply and as a by-product from sugar production, and KOH and phosphoric acid are recommended as the final waste (potassium phosphate) is important fertilizer. Therefore, to attain the utmost benefits, scrutinizing the means to acquire KOH and phosphoric acid at lower costs are the most beneficial.

Product quality is the major factor that determine the widespread use of biodiesel fuel, especially for local production and use. Therefore, since the concept and principles of biodiesel production is novel to the country, it is essential to establish the product quality standardization, pertinent to the country, that agree with the internationally accepted standard specifications as ASTM and EN.

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ASTM 2
ASTM 3

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MoA


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Sharp
2
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2007-07-12

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Zhang
1
Zhang
2

APPENDICES
Appendix A

Data from Literature and Field Assessment

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Appendix 1: Major Fatty Acid Compositions of oils, their Methyl Esters and Effects on Fuel Properties

Source:

Adopted from-(Sober, 1970; Knothe et al., 1997; Gurr et al., 2002; Knothe, 2003, 2005; Van Gerpen et al., 2004;)

\[a\]
760mmHg unless otherwise specified.

\[b\]
At temperature indicated in superscript, referred to water at 4°C.

\[c\]
Milligrams of KOH required to neutralize one gram of acid.

\[d\]
Grams of Iodine absorbed by 100 grams of acid.

<table>
<thead>
<tr>
<th>Trivial/Systematic/name;/Formula/</th>
<th>Acronym/Methyl ester</th>
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</thead>
<tbody>
<tr>
<td>Molecular Weight</td>
<td></td>
</tr>
<tr>
<td>Melting Point</td>
<td></td>
</tr>
<tr>
<td>(o C)</td>
<td></td>
</tr>
<tr>
<td>Boiling Point</td>
<td></td>
</tr>
<tr>
<td>(a)</td>
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</table>

<table>
<thead>
<tr>
<th>Saturated Fatty Acids</th>
<th>Acid Value</th>
<th>Iodine Value</th>
<th>Cetane Number</th>
<th>Viscosity (40°C, mm²/s)</th>
<th>Heat of Combustion (Kcal/mol at 25°C)</th>
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<tbody>
<tr>
<td>Lauric/dodecanoic/C12H24O2/C12:0/</td>
<td>200.3</td>
<td>44.2</td>
<td>225/100</td>
<td>0.8690</td>
<td>50 280.1 - 1763.25</td>
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<td>Methyl laurate</td>
<td>214.34</td>
<td>4.8</td>
<td>266</td>
<td>61.4</td>
<td>1.95</td>
</tr>
<tr>
<td>Myristic/Tetradecanoic/C14H28O2/C14:0/</td>
<td>2073.91</td>
<td>63.1</td>
<td>268/100</td>
<td>0.88487</td>
<td>70 218.8 - 2384.76</td>
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<tr>
<td>Methyl myristate</td>
<td>242.40</td>
<td>18</td>
<td>250.5</td>
<td>2.69</td>
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<tr>
<td>Palmitic/Hexadecanoic/C16H32O2/C16:0/</td>
<td>2384.76</td>
<td></td>
<td></td>
<td>256.4</td>
<td>63.1</td>
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<td>Mol. Wt.</td>
<td>172</td>
<td>p.d.1</td>
<td>174</td>
<td>175</td>
<td>176</td>
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<td>-----</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
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<td>270.4</td>
<td>32.34</td>
<td>163</td>
<td>74.5</td>
<td>3.6</td>
<td>2550.00</td>
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<tr>
<td>284.5</td>
<td>69.6</td>
<td>213/5</td>
<td>0.8390</td>
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<tr>
<td>197.2</td>
<td>61.7</td>
<td>2696.12 Stearic/Octadecanoic/C18H36O2/C18:0/ Methyl stearate 298.5 39 215</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>86.9</td>
<td>4.74</td>
<td>2859.00 Unsaturated Fatty Acids (Monoethenoic) 282.5 13.4 16.3 234/15 0.8905 20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>298.6</td>
<td>89.9</td>
<td>46.1  2657.40 Oleic/ cis-9-Octadecenoic /C18H34O2/C18:1/ Methyl oleate 296.5 -20 218.5 55 3.73 2828.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>198.6</td>
<td>89.9</td>
<td>Erucic/13-Docosenoic/ C22H42O2/C22:1/ Methyl erucate 221 5.91 3454</td>
<td></td>
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</table>
| 221     |      5.91 3454 Unsaturated Fatty Acids (Dienoic) 280.5 -5.2 to -5.0 229 0.8938 18 200.1 181.0 31.4 a-Linoleic/cis-9,cis-12-Octadecadienoic /C18H32O2/C18:2/ Methyl linoleate 294.5 -35 215 42.2 3.73 Unsaturated Fatty Acids (Trienoic) 278.4 -10 to -11.3 157/0.001 0.914 20 201.5 273.5 20.4 a-Linolenic/cis-9,cis-12-cis-15-Octadecatrienoic /C18H30O2/C18:3/ Methyl linolenate 292.5 182 22.7 Hydroxy Fatty Acids 298.5 5.77, 16 225/10 0.940 27.4 188.0 85.0 Ricinoleic/d-12-Hydroxy-cis-9-octadecenoic /C18H34O3/C18:1/ Methyl ricinoleate
Appendix 1: Biodiesel Standards Specification

Source: Adoped from
(Biodiesel Industries Australia, 2003)

<table>
<thead>
<tr>
<th>Specification / Standard</th>
<th>USA</th>
<th>EU Recommended</th>
<th>Test Method</th>
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<td>Property Unit</td>
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<td>ASTM D 6751 EN 14214</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Density 15°C Kg/m</td>
<td>3</td>
<td>- 860 -900</td>
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<tr>
<td>Kinematic Viscosity</td>
<td>2</td>
<td>1.9-6.0 3.5-5.0</td>
<td>1.9-6.0 3.5-5.0 ASTM D 445</td>
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<tr>
<td>Distillation 95 % Å°C</td>
<td>≤ 360</td>
<td>-</td>
<td>≤ 360 ASTM D 1160</td>
</tr>
<tr>
<td>Flashpoint Å°C</td>
<td></td>
<td>≥ 120</td>
<td>≥ 130 STM D 93</td>
</tr>
<tr>
<td>Summer Å°C - Å°C</td>
<td>5</td>
<td>-5 / Å° ≤0</td>
<td></td>
</tr>
<tr>
<td>Spr / Aut Å°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter Å°C - Å°</td>
<td>-15</td>
<td>-10 / Å° ≤20</td>
<td></td>
</tr>
<tr>
<td>Cloud Point Å°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Sulphur 100%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>w% Å° ≤0.05 Å° ≤0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100% w% Å° ≤0.05</td>
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<td></td>
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</tr>
<tr>
<td>10% w% Å° ≤0.05 Å° ≤0.30</td>
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<td></td>
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<tr>
<td>Sulphated Ash w%</td>
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</tr>
<tr>
<td>Å° ≤0.02 Å° ≤0.02</td>
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</table>

ASTM D 874
Water Content mg/kg - ≤ 500
Total Contamination mg/kg - ≤ 24
Water and Sediment % vol ≤ 0.05 - ASTM D 2709
Corrosion (cu) 3h @ 50 Å°c
No.3 Class 1 ASTM D 130
Cetane No. ≥ 47 ≥ 51 ASTM D 613
Acid No. Mg KOH/g ≤ 0.8
ASTM D 664
Oxidation Stability 110 Å°c
hours
6
Methanol Content %w%
Ester Content % w% ≥ 96.5
Triglycerides % w% ≤ 0.20
Diglycerides % w% ≤ 0.20
Monoglyceride % w% ≤ 0.80
Free Glycerol % w% ≤ 0.02 ≤ 0.02 ASTM D 6584
Total Glycerol % w% ≤ 0.24 ≤ 0.25 ASTM D 6584
Iodine Value gI/100g ≤ 120
Phosphorous mg/kg ≤ 10 ASTM D 4951
Alkaline Metals mg/kg ≤ 5
Linolenic acid methyl ester % w% ≤ 12
Polyunsaturated Methyl esters % w%
I 1
Appendix 2: Ethiopian Sugar Industries: Ethanol Production and Projection
Ethanol (Million L)
Fincha'aa® 8.00 8.448 11.009 13.834 16.585 18.515 21.221
Matahara - - 7.311 11.700 11.700 28.183 35.527
Appendix 3: Volume and Value of Petroleum Import of Ethiopia

(a) Aggregate of Petroleum Products Import and Consumption

<table>
<thead>
<tr>
<th>Year</th>
<th>VOLUME OF IMPORTED OIL (TON)</th>
<th>VALUE (000BIRR)</th>
<th>VOLUME INCREMENT %</th>
<th>VALUE INCREMENT %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1,023,676</td>
<td>1,876,700</td>
<td>1.2</td>
<td>77</td>
</tr>
<tr>
<td>2001</td>
<td>1,096,447</td>
<td>2,373,768</td>
<td>7</td>
<td>27</td>
</tr>
<tr>
<td>2002</td>
<td>1,122,223</td>
<td>2,066,113</td>
<td>2.4</td>
<td>-13</td>
</tr>
<tr>
<td>2003</td>
<td>1,232,379</td>
<td>2,683,934</td>
<td>9.8</td>
<td>23</td>
</tr>
<tr>
<td>2004</td>
<td>1,248,092</td>
<td>3,217,028</td>
<td>1.2</td>
<td>27</td>
</tr>
<tr>
<td>2005</td>
<td>1,406,899</td>
<td>5,288,832</td>
<td>12.7</td>
<td>64.4</td>
</tr>
<tr>
<td>2006</td>
<td>1,478,001</td>
<td>6,883,638</td>
<td>5.1</td>
<td>30.1</td>
</tr>
<tr>
<td>2007</td>
<td>1,610,215</td>
<td>7,706,157</td>
<td>116.4</td>
<td>42.3</td>
</tr>
</tbody>
</table>

(b) Percentage Share of Each Component (for the year 2006/077)

<table>
<thead>
<tr>
<th>Year</th>
<th>LPG Ton</th>
<th>MGR Ton</th>
<th>Kerosene/Jet F Gasoil Ton</th>
<th>LFO Ton</th>
<th>HFO Ton</th>
<th>Total Ton</th>
<th>LPG USD</th>
<th>MGR USD</th>
<th>Kerosene/Jet F Gasoil USD</th>
<th>LFO USD</th>
<th>HFO USD</th>
<th>Total USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006/7</td>
<td>0</td>
<td>0</td>
<td>143,743</td>
<td>84,245,805</td>
<td>402,311.30</td>
<td>246,366,769.20</td>
<td>905,477.80</td>
<td>519,146,278.80</td>
<td>42,254.80</td>
<td>14,291,536.30</td>
<td>116,428.90</td>
<td>38,139,482.20</td>
</tr>
<tr>
<td>%</td>
<td>0</td>
<td>0</td>
<td>8.93</td>
<td>9.34</td>
<td>24.98</td>
<td>27.31</td>
<td>56.23</td>
<td>57.54</td>
<td>2.62</td>
<td>1.58</td>
<td>7.23</td>
<td>4.23</td>
</tr>
</tbody>
</table>

Appendix 4: Biodiesel Investment in Ethiopia-Area and Status

<table>
<thead>
<tr>
<th>No.</th>
<th>Company name</th>
<th>Area requested (ha)</th>
<th>Region</th>
<th>Origin of the Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flora ECCO Power</td>
<td>15000</td>
<td>Oromia</td>
<td>Germany &amp; Israel</td>
</tr>
<tr>
<td>2</td>
<td>Sun Biofuel</td>
<td>50000</td>
<td>SNNRS</td>
<td>England</td>
</tr>
<tr>
<td>3</td>
<td>LHBCHATZ</td>
<td>100000</td>
<td>Oromia</td>
<td>Israel</td>
</tr>
<tr>
<td>4</td>
<td>BECCO Company</td>
<td>3000</td>
<td>SNNRS</td>
<td>Ethiopia</td>
</tr>
<tr>
<td>5</td>
<td>Villar Energy Co.</td>
<td>100000</td>
<td>Afar &amp;</td>
<td>Oromia &amp; Israel</td>
</tr>
<tr>
<td>6</td>
<td>RINA International Investment</td>
<td>80000</td>
<td>Oromia -</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Kenya Bioenergy Limited</td>
<td>100000</td>
<td>South Africa</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Gento Consulting Ltd</td>
<td>100000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>Global Trinity group</td>
<td>100000</td>
<td>-</td>
<td>- USA</td>
</tr>
<tr>
<td>10</td>
<td>Ethan</td>
<td>100000</td>
<td>BGRS &amp;</td>
<td>SNNRS Ethiopia</td>
</tr>
<tr>
<td>11</td>
<td>Beta</td>
<td>100</td>
<td>SNNRS</td>
<td>Ethiopia</td>
</tr>
<tr>
<td>12</td>
<td>Asossa Association of Biofuels</td>
<td>10000</td>
<td>BGRS</td>
<td>Ethiopia</td>
</tr>
<tr>
<td>13</td>
<td>FRI-EL-Green Power</td>
<td>30000</td>
<td>SNNRS</td>
<td>Italy</td>
</tr>
</tbody>
</table>

Total 698,100

Source: MoME, 2007

Appendix 5: Land-use Land-Cover of Ethiopia

<table>
<thead>
<tr>
<th>No.</th>
<th>Land use</th>
<th>Land Cover</th>
<th>Area in ha</th>
<th>Coverage in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cultivation</td>
<td></td>
<td>21,298,241</td>
<td>18.7</td>
</tr>
<tr>
<td>2</td>
<td>Vegetation land</td>
<td>High forest (inc. ravine)</td>
<td>4,073,213</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plantation</td>
<td>501,522</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Woodland</td>
<td>29,242,949</td>
<td>25.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shrub land</td>
<td>26,400,200</td>
<td>23.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Highland bamboo</td>
<td>31,003</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lowland bamboo</td>
<td>494,564</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grass land</td>
<td>14,574,206</td>
<td>12.8</td>
</tr>
<tr>
<td>4</td>
<td>Afro-alpine</td>
<td></td>
<td>245,328</td>
<td>0.2</td>
</tr>
<tr>
<td>5</td>
<td>Swamp</td>
<td></td>
<td>755,181</td>
<td>0.7</td>
</tr>
<tr>
<td>6</td>
<td>Water</td>
<td></td>
<td>828,277</td>
<td>0.7</td>
</tr>
<tr>
<td>7</td>
<td>Bare rock, soil, etc.</td>
<td></td>
<td>15,357,720</td>
<td>13.5</td>
</tr>
<tr>
<td>8</td>
<td>Urban</td>
<td></td>
<td>71,965</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Total 113,874,369

Appendix 6: Traditional Agroclimatic Zones and their physical characteristics

Appendix 7: Thermal Zones of Ethiopia
Appendix 8: Available effective rainy period in days (RF-mm)
No. Zones
Altitude (metres)
Rainfall (mm/year)
Average Annual temperature (°C)

1 Wurch (cold and moist) 3200 plus 900 2200 <11.5
2 Dega (cool and humid) 2300 3200 900 1200 17.5/16.0 11.5
3 Weyna Dega (cool sub-humid) 1500 2300/2400 800 1200 20.0 17.5/16.0
4 Kola (warm semi-arid) 500 1500/1800 200 800 27.5 20
5 Berha (hot arid) under 500 under 200 >27.5

Source: MoA, 2000 as sited in Alemneh Dejene, 2003

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Appendix 9: Agronomic and morphological characteristics of B. carinata

Source: MoARD (2005)
Plant Species Name/ Variety
B. carinata
Agronomic and Morphological Characteristics
MS-YD X Zem-1-
BCR-5(Holetta-1)
Acc. 153
(Hawassa I)
PGRC/E/1/2/208507
(Hawassa II)
Adaptation Area High lands of Shewa, Arsi, Bale & Gojjam)
Awassa, Kokate, Hossina, Hagereselam, Waka
Awassa, Kokate, Hossina, Hagereselam, Bule
Altitude (m.a.s.l.) 2000-2600 1700-2400 1700-2700
Rainfall (mm) 600-900 800-1200 800-1200
Seed rate (Kg/ha) 20 10 10
Planting date Early June â€“ early July
Early to mid July
Early to mid July
P
2
O
5
69 69 69 Fertilizer rate
(kg/ha) N 46 46 46
Days of flowering 75 83 70
Days of maturity 160 144 121
Plant height (cm)  175  175  147
Growth habit Erect (upright) Erect (upright) Erect (upright)
1000 seed wt (g)  4.5  3.7  3.3
Seed color Mixed (yellow & brown)
Light yellow Yellow
Flower color Yellow Yellow Yellow
Pod color at maturity Red Brown Brown
Pods per plant  270  229  240
Research field  30.30  9.40  10.6 Yield
(Q/ha) Farmer field -  7.00  7-7.5
Average oil content (%)  39.10  37.60  33.5
Average oil yield (Kg/ha)  1184  335.1  355
Biochemical characteristics  22-25% Erucic acid - -
Year of release  2005  2006
Breeder/maintainer HARC/EARO AWARC/SARI

Appendix B

TBULATED DATA ON EXPERIMENTS

<table>
<thead>
<tr>
<th>Code</th>
<th>Repl</th>
<th>Plate</th>
<th>wt (g)</th>
<th>before drying</th>
<th>Oil (%w/w) with plate</th>
<th>Oil (%w/w)</th>
</tr>
</thead>
</table>

Moisture content (%w/w) Seed Oil Content (%w/w)
<table>
<thead>
<tr>
<th>Sample wt (g) dry base</th>
<th>Wt of empty flask (g)</th>
<th>Wt of oil (g)</th>
<th>Dry base</th>
<th>Wet base</th>
<th>Av dry base</th>
<th>Meal (w%)</th>
<th>Wet Color of oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rc-1</td>
<td>3.160 5.964 0.14 2.94 4.63 200.3 191.03 171.7 243.3 71.6 37.48 35.75 64.25</td>
<td>3.225 6.344 0.15 3.12 4.81 200.3 190.67 297.4 371.4 74.81 36.94 63.06</td>
<td>3.267 6.266 0.15 3.00 5.00 4.81 159.7 151.71 298.2 372.5 74.3 48.97 46.52 39.7 53.48</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rc-2</td>
<td>3.215 6.158 5.972 0.19 2.94 6.32 103.7 97.146 297.4 341.5 44.1 45.4 42.53 57.47</td>
<td>3.25 6.293 0.19 3.04 6.08 102.6 96.362 298 346.5 48.5 50.33 47.27 52.73</td>
<td>3.263 6.325 6.137 0.19 3.06 6.14 155.2 145.67 297.6 371.3 73.7 50.59 47.49 45.8 52.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rc-3</td>
<td>3.258 6.561 6.315 0.25 3.30 7.45 174.2 161.23 297 362.9 65.9 40.87 37.83 62.17</td>
<td>3.214 6.522 6.290 0.23 3.31 7.01 138.2 128.51 172.5 220.4 47.9 37.27 34.66 65.34</td>
<td>3.234 6.374 6.140 0.23 3.14 7.45 7.30 172.8 159.92 297.6 361.3 63.7 39.83 36.86 63.5 63.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rc-4</td>
<td>3.161 6.213 5.961 0.25 3.05 8.26 46.8 42.936 167.7 185.9 18.2 42.39 38.89 61.11</td>
<td>3.231 6.116 5.882 0.23 2.89 8.11 42.4 38.961 167.1 183.6 16.5 42.35 38.92 61.08</td>
<td>3.37 6.246 6.012 0.23 2.98 7.86 8.08 23.4 21.56 151.3 162.6 11.3 52.41 48.29 42.51 51.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rc-5</td>
<td>3.257 6.901 6.626 0.27 3.64 7.55 104.3 96.429 297 337 40 41.48 38.35 61.65</td>
<td>3.21 6.99 6.707 0.28 3.78 7.49 96.4 89.183 301.2 339.2 38 42.61 39.42 60.58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Moisture and Seed Oil Content (%w/w)

<table>
<thead>
<tr>
<th>Code</th>
<th>Repl</th>
<th>Plate wt (g)</th>
<th>Oil (%w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bc-1</td>
<td>1</td>
<td>3.257 6.514</td>
<td>6.307 0.21</td>
</tr>
<tr>
<td>2</td>
<td>3.267</td>
<td>6.4 6.211</td>
<td>0.19 3.13 6.03 137.2 128.92 298.9</td>
</tr>
<tr>
<td>3</td>
<td>3.194</td>
<td>6.574 6.367</td>
<td>0.21 3.38 6.12</td>
</tr>
</tbody>
</table>

Orange brown

**Appendix 10:** Tabulated data on experiments—moisture and seed oil content (%w/w) determination

**Appendix 11:** Tabulated data on experiments—moisture and seed oil content (%w/w) continued

<table>
<thead>
<tr>
<th>Code</th>
<th>Repl</th>
<th>Plate wt (g)</th>
<th>Oil (%w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Moisture content (%w/w) Seed Oil Content (%w/w)

- Sample wt (g)
- with plate Oil (%w/w)
- Code Repl
- Plate
- wt (g) before drying
- After drying Difference
- Wt of wet sample (g)
- Moisture content (%w/w)
- Av moisture content (%w/w)
- Sample wt (g) wet base
- Sample wt (g) dry base
- Wt of empty flask (g)
- Wt of oil + empty flask (g)
- Wt of oil (g)
- Dry base
- Wet base
Appendix 11: GC results of fatty acid compositions of pure and blends of the oils

Table (a)  Pure oils
Fatty Acid Composition (w%) Fatty acids (Carbon No. & No. double bonds)
B.carinata R.communis J.curcas E.guineensis
Palmitic (16:0) 2.83 Â± 0.12 1.23 Â± 0.29 11.23 Â± 0.46 42.93 Â± 0.58
Stearic (18:0) 1.53 Â± 0.45 1.03 Â± 0.09 17 Â± 0.12 4.17 Â± 0.6
Oleic (18:1) 16.43 Â± 0.92 4.37 Â± 0.42 12.3 Â± 0.66 41.17 Â± 2.0
Linoleic (18:2) 5.2 Â± 0.4 47.1 Â± 0.58 10.03 Â± 0.58
Linolenic (18:3) 21.2 Â± 0.69 0.27 Â± 0.12
Ricinoleic(18:1) 87.97 Â± 0.87
Arachidic (20:0) 4.63 Â± 0.35
Arachideic (20:1) 10.76 Â± 0.6
Erucic(22:1) 44.2 Â± 0.75
Unidentified 3.05 0.2 7.74 1.43
### Table (b) Blends

<table>
<thead>
<tr>
<th>Fatty Acid Compositions of the blends of biodiesels</th>
<th>Fatty acids (Carbon No.&amp; No. double bonds)</th>
<th>Bc100</th>
<th>Eg5Bc95</th>
<th>Eg10Bc90</th>
<th>Eg20Bc80</th>
<th>Eg50Bc50</th>
<th>Eg100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmitic (16:0)</td>
<td>2.83 ± 0.12</td>
<td>4.26 ± 0.14</td>
<td>5.1 ± 0.25</td>
<td>7.8 ± 0.03</td>
<td>18.6 ± 0.27</td>
<td>44.4 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>Stearic (18:0)</td>
<td>1.53 ± 0.45</td>
<td>1.3 ± 0.11</td>
<td>1.4 ± 0.05</td>
<td>1.7 ± 0.05</td>
<td>6.2 ± 0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oleic (18:1)</td>
<td>16.43 ± 0.92</td>
<td>16.3 ± 0.09</td>
<td>13.2 ± 0.15</td>
<td>20.67 ± 0.09</td>
<td>25.7 ± 0.25</td>
<td>45.57 ± 0.26</td>
<td></td>
</tr>
<tr>
<td>Linoleic (18:2)</td>
<td>21.2 ± 0.69</td>
<td>20.47 ± 0.09</td>
<td>22.57 ± 0.24</td>
<td>16.83 ± 0.09</td>
<td>15.83 ± 0.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linolenic (18:3)</td>
<td>0.9 ± 0.06</td>
<td>0.93 ± 0.09</td>
<td>1.83 ± 0.03</td>
<td>1.63 ± 0.03</td>
<td>1.67 ± 0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arachidic (20:0)</td>
<td>10.76 ± 0.6</td>
<td>11.7 ± 0.06</td>
<td>11.53 ± 0.27</td>
<td>8.83 ± 0.03</td>
<td>6.97 ± 0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arachideic (20:1)</td>
<td>44.2 ± 0.75</td>
<td>42.53 ± 0.14</td>
<td>42.5 ± 0.06</td>
<td>38.73 ± 0.09</td>
<td>31.6 ± 0.6</td>
<td>0.4 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>Unidentified (trace)</td>
<td>3.05</td>
<td>2.62</td>
<td>2.13</td>
<td>3.80</td>
<td>0.19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Eg5Bc95ME = 5% E. guineensis + 95% B. carinata
Eg10Bc90ME = 10% E. guineensis + 90% B. carinata
Eg20Bc80ME = 20% E. guineensis + 80% B. carinata
Eg50Bc50ME = 50% E. guineensis + 50% B. carinata
Rc10Bc90ME = 10% R. communis + 90% B. carinata
Rc10Jc90ME = 10% R. communis + 90% J. curcas
Bc100 = 100% B. carinata
Eg 100 = 100% E. guineensis

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Appendix 12: ANOVA

Moisture content

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>8</td>
<td>5.540</td>
<td>17.513</td>
</tr>
<tr>
<td>Within Groups</td>
<td>18</td>
<td>.316</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>50.017</td>
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</tbody>
</table>
### Oil content

<table>
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<tr>
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<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>976.231</td>
<td>8</td>
<td>122.029</td>
<td>7.105</td>
<td>.000</td>
</tr>
<tr>
<td>Within Groups</td>
<td>309.144</td>
<td>18</td>
<td>17.175</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1285.375</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

### Density

<table>
<thead>
<tr>
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<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>.014</td>
<td>4</td>
<td>.004</td>
<td></td>
<td>.000</td>
</tr>
<tr>
<td>Within Groups</td>
<td>.000</td>
<td>10</td>
<td>.000</td>
<td></td>
<td>.000</td>
</tr>
<tr>
<td>Total</td>
<td>.014</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Viscosity

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>266.319</td>
<td>4</td>
<td>66.580</td>
<td>32009.524</td>
<td>.000</td>
</tr>
<tr>
<td>Within Groups</td>
<td>.021</td>
<td>10</td>
<td>.002</td>
<td></td>
<td></td>
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<tr>
<td>Total</td>
<td>266.340</td>
<td>14</td>
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Flash point

Sum of
Squares df Mean Square F Sig.
Between Groups
34610.970 4 8652.743 2403.326 .000
Within Groups
36.003 10 3.600
Total
34646.973 14

Oil
a
Vs moisture
b
content
Model Sum of Squares df Mean Square F Sig.
1 Regression
2.093 1 2.093 1.092 .306
Residual
47.925 25 1.917
Total
50.017 26
a Predictors: (Constant), Oil content
b Dependent Variable: Moisture content

94

Cloud point

Sum of
Squares df Mean Square F Sig.
Between Groups
1646.400 4 411.600 329.280 .000
Within Groups
12.500 10 1.250
Total
1658.900 14

Cetane number

Sum of
Squares df Mean Square F Sig.
Between Groups
33.746 4 8.436 16872.780 .000
Within Groups
.005 10 .001
Total
33.751 14
Acid value

<table>
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<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>5.640</td>
<td>4</td>
<td>1.410</td>
<td>44061.113</td>
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<tr>
<td>Within Groups</td>
<td>.000</td>
<td>10</td>
<td>.000</td>
<td></td>
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<tr>
<td>Total</td>
<td>5.640</td>
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Iodine value

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<th>Sig.</th>
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<td>19278.144</td>
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<td>4819.536</td>
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<td>.162</td>
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<td>.016</td>
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<td>Total</td>
<td>19278.306</td>
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95

Appendix 13: Continuous Base-catalyzed Biodiesel Production Process
Appendix 14: The Gas chromatograms of the standard reference material

Appendix 15: The chromatograms of the samples analyzed
J. curcas

<table>
<thead>
<tr>
<th>[min.]</th>
<th>Time</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>[mV]</td>
<td>Vo</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td>250</td>
<td>300</td>
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</tbody>
</table>

fatty acid, 2 - Detector 2

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<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>[V]</td>
<td>V</td>
<td>0.0</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
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BCME-1 - Detector 2

<table>
<thead>
<tr>
<th>Time [min.]</th>
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<tr>
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<tr>
<td>10</td>
<td>0.1</td>
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<tr>
<td>20</td>
<td>0.2</td>
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<tr>
<td>30</td>
<td>0.3</td>
</tr>
<tr>
<td>40</td>
<td>0.4</td>
</tr>
<tr>
<td>50</td>
<td>0.5</td>
</tr>
<tr>
<td>60</td>
<td>0.6</td>
</tr>
<tr>
<td>Time</td>
<td>0</td>
</tr>
<tr>
<td>------</td>
<td>----</td>
</tr>
<tr>
<td>B. carinata</td>
<td></td>
</tr>
<tr>
<td>R. communis</td>
<td></td>
</tr>
</tbody>
</table>

[min.]
J. curcas

97

E. guineesis
[min ]
0 10 20 30 40 50 60
[V]
Vo
ta
g
e
0.0
0.2
0.4
0.6
0.8
1.0
1.2
P10BC90 - Detector 2
42
.277
46
.8
57
C
1
8:
3
46.
96
0
47
.353
51.
540
51.
9
07 C
20
57.
2
00 C
22
6
4
.2
7
3
<table>
<thead>
<tr>
<th>Time (min.)</th>
<th>P50BC50 - Detector 1</th>
<th>P50BC50 - Detector 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>46.38</td>
<td>51.183</td>
</tr>
<tr>
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<td>42.38</td>
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<td>20</td>
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<td>51.183</td>
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<tr>
<td>60</td>
<td>46.38</td>
<td>51.183</td>
</tr>
</tbody>
</table>
1.2
EgME - Detector 1
EgME - Detector 2
36.
680 C
14
42.
540 C
16
43.
390
47.
040
47.
473 C
18:
0
51.
933 C
20
56.
517

[min.]
Time
0 10 20 30 40 50 60
[V]
Vol
ta
g
e
0.0
0.2
0.4
0.6
0.8
1.0
1.2 RC10BC90 - Detector 1
RC10BC90 - Detector 2
4
2
.4
3
7
4
6.
9
73
5
1.
7
37