EVALUATION OF QUANTITY AND QUALITY OF BIODIESEL PRODUCED FROM *Jatropha curcas* IN DIFFERENT PARTS OF KENYA

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A thesis submitted in partial fulfilment of the requirements for the award of the degree of Master of Science (Biochemistry) in the School of Pure and Applied Sciences of Kenyatta University.

May 2015
DECLARATION

This thesis is my original work and has not been presented for a degree in any other university or any other award.

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Signature...........................Date................................

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DEDICATION

To my family who have tirelessly supported and encouraged me throughout my research.
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
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<tr>
<td>CDM</td>
<td>Clean Development Mechanism</td>
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<tr>
<td>CER</td>
<td>Certified Emission Reductions</td>
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<tr>
<td>EC</td>
<td>European Commission</td>
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<tr>
<td>FFA</td>
<td>Free fatty acid</td>
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<tr>
<td>GHG</td>
<td>Greenhouse gas</td>
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<tr>
<td>GTZ</td>
<td>German Technical Cooperation</td>
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<td>JCL</td>
<td><em>Jatropha curcas</em> Linnaeus</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquid petroleum gas</td>
</tr>
<tr>
<td>MC</td>
<td>Moisture content</td>
</tr>
<tr>
<td>SJO</td>
<td>Straight jatropha oil</td>
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<tr>
<td>SVO</td>
<td>Straight vegetable oil</td>
</tr>
<tr>
<td>VO</td>
<td>Vegetable oil</td>
</tr>
<tr>
<td>WCO</td>
<td>Waste cooking oil</td>
</tr>
<tr>
<td>WVF</td>
<td>Waste vegetable fat</td>
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<td>WWF</td>
<td>World Wildlife Fund</td>
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ABSTRACT

Biodiesel as an alternative fuel for diesel engines is becoming increasingly important due to diminishing petroleum reserves and the environmental consequences of exhaust gases from petroleum-fuelled engines. The availability and sustainability of sufficient supplies of less expensive feedstock will be a crucial determinant delivering a competitive biodiesel to the commercial filling stations. Fortunately, inedible vegetable oils, mostly produced by seed-bearing trees and shrubs can provide this much desired alternative. With no competing food uses, this characteristic makes *Jatropha curcas* a preferred alternative. *Jatropha curcas* is a non-edible oil crop predominately used to produce bio-diesel. The seeds contain 27-40% oil (average: 34.4%) that can be processed to produce a high-quality biodiesel fuel, usable in a standard diesel engine. There is need therefore to determine the jatropha with the highest quality and quantity to be developed. The objective of this study was to evaluate the characteristics of biodiesel produced from *Jatropha curcas* oil in Kenya using trans-esterification process. Straight jatropha oil was extracted and its physical and chemical properties analysed. The oil was transesterified to produce its methyl ester which is jatropha biodiesel. The physical and chemical properties were analysed and compared to the standard requirements. From the results obtained, straight Jatropha oil was unsuitable for direct usage as fossil fuel substitute but had to undergo trans-esterification to produce biodiesel. For instance the density of Jatropha seed oil was between 1.0802 - 1.0864 g/cm\(^3\) at 20°C whereas that of biodiesel was in the range of 0.8786–0.8808 g/cm\(^3\), the standard for biodiesel states that the fuel should have a density between 0.860 and 0.900 g/cm\(^3\). Acid value of Jatropha oil was between 1.35 - 4.19 mgKOH/g and that of the biodiesel was between 0.31 - 0.86 mgKOH/g, kinematic viscosity of biodiesel was between 4.3 to 4.8mm\(^2\)/s at 40°C. The parameters of the biodiesel produced were in agreement with ASTM standards of biodiesel and is a suitable substitute for fossil fuel.
CHAPTER ONE

INTRODUCTION

1.1 Background

Petroleum is the largest single source of energy consumed by the world’s population, exceeding coal, natural gas, nuclear, hydro and renewables. The increasing industrialization and modernization of the world has led to a steep rise in the demand of petroleum products. Global demand for petroleum is predicted to increase 40% by 2025. Economic development in developing countries has led to huge increase in energy demand. In India, the energy demand is increasing at a rate of 6.5% per annum. The crude oil demand of the country is met by import of about 80% (Jain and Sharma, 2010).

Kenya spends over 40% of its foreign exchange earnings on importing crude oil and other petroleum products (GTZ, 2008). The total petroleum consumption in Kenya has grown from 2.6 million cubic meters in 2003 to 3.73 million cubic meters in 2006. Consumption of liquid petroleum gas (LPG) has increased by about 61% between 2003 and 2006 from 40,000 to 65,000 metric tons per year. The Kenya petroleum refinery makes about 30,000 metric tons of LPG and to balance demand reliance on imported LPG has increased, thus the energy security has become a key issue for the nation as a whole (GTZ, 2008).

Petroleum-based fuels are limited. The finite reserves are highly concentrated in certain regions of the world. Therefore, those countries without these reserves are facing foreign exchange crises, mainly due to the import of crude oil. Petroleum got limited resource and there is a possibility that petroleum sources will run out for the coming decades. Based on studies, almost half of oil reserves have been utilized and that is about two
trillion barrels and only one trillion barrels are left. There might be some other sources of petroleum in the world but experts are afraid that these sources cannot produce enough oil or petroleum to sustain human needs. Processing and extracting oil can also contribute to pollution and environmental degradation. It is known that emissions from the combustion of these fuels such as carbon dioxide ($CO_2$), carbon monoxide (CO), nitrogen oxides (NOx) and sulphur-containing residues are the principal causes of global warming and other environmentally related impacts and many countries have passed legislations in their production so as to arrest their adverse environmental consequences (Sheehan et al., 1998). The expected 52% rise in world carbon dioxide emissions by 2030 further highlights the risk of reliance on a single commodity for so much of the world’s energy needs especially with the emissions of fossil fuels (including petroleum) already linked to global climate change.

Petroleum oil is said to be non-renewable resource, meaning once individuals consumed a portion of this, there will be no replacement. In the long run, this may also cause depletion and this can no longer be regenerated once depleted. Oil spill is another disadvantage linked to petroleum. If oil or petroleum spills, adverse effects in oceans and marine life can be expected. Hence it is necessary to look for alternative sources of fuels, which can be produced from feedstock available within the country. Biodiesel, an eco-friendly and renewable fuel substitute for diesel has been getting the attention of researchers/scientists all over the world (GTZ, 2008). Biodiesel, derived from vegetable oil is recommended for use as a suitable substitute for petroleum-based diesel mainly because biodiesel is a renewable, domestic resource with an environmentally friendly emission profile and is readily biodegradable. The use of biodiesel has grown
dramatically during the last few years and is becoming a key component in the motor diesel pool, because of its attractive features. Besides, the biodiesel technology and market is highly prospective (Sheehan et al., 1998).

Concerns about oil supply and energy security have motivated many countries to consider alternatives to imported petroleum. Liquid biofuels, renewable fuels derived from biomass, are arguably one of the best options to lead the transition away from petroleum fuels in the near-term and have made a recent resurgence in response to rising oil prices. However, biofuels present resource and environmental challenges depending on where, how and from which feedstock they are developed. The global rise in the price of petroleum prices and interest in renewable energy sources has resulted in increased interest in all types of biofuels across the developing world. Like other African countries, Kenya has seen a great increase in promotion of *Jatropha curcas*, a naturalized shrub that produces non-edible oil suitable for biodiesel. Both private companies and non-governmental organizations are involved, claiming potential benefits for energy security, greenhouse gas mitigation and rural development. Although biodiesel has experienced episodes of popularity throughout the 20th century, the most recent biodiesel revival began in Europe in the early 1990’s, spurred by mandatory alternative fuel use legislation and a liquid fuel market dominated by diesel fuel (66% of on-road, liquid fuel demand). As of 2004, Europe’s biodiesel production has grown to over 2.0 billion litres, compared with U.S. production of only 100million litres per year. Together, the European Union and the U.S. jointly account for over 95% of the global biodiesel demand. In addition, Canada, Australia, South Africa, Japan, China, India, Brazil, Thailand, Malaysia and Indonesia all have small commercial biodiesel programs and many more in the research
phase. Although the technical details of biodiesel have been thoroughly studied, there has been less focus on what constitutes a strategic deployment.

Biodiesel is a non-toxic, biodegradable, renewable fuel that can be produced from a range of organic feedstock including fresh or waste vegetable oils, animal fats, and oilseed plants. Biodiesel has significantly lower carbon emissions than petroleum-based diesel when it is burned, whether used in its pure form or blended with petroleum diesel. It does not contribute to a net rise in the level of carbon dioxide in the atmosphere and leads to minimized intensity of greenhouse effect (Vicente et al., 2004). In addition, biodiesel is better than diesel fuel in terms of sulphur content, flash point, aromatic content and biodegradability (Martini and Schell, 1998). Vegetable oils are becoming a promising alternative to fossil diesel fuel because they are renewable in nature and can be produced locally; and are also environmentally friendly. Fortunately, inedible vegetable oils, mostly produced by seed-bearing trees and shrubs can provide this much desired alternative. With no competing food uses, this characteristic makes J. curcas a preferred alternative.

The oil from J. curcas is non-edible, however, it has the potential to provide promising and commercially viable alternative to fossil diesel oil as it has most of the desirable physicochemical and performance characteristics as that of fossil diesel (Tomomatsu and Swallow, 2007). The plant J. curcas has lately attracted particular attention as a tropical energy plant. The seed oil can be used as diesel engine fuel since it has characteristics close to those of fossil fuel diesel. Moreover, due to its non-toxic and biodegradable nature, Jatropha biodiesel meets the European EN14214 standards of a pure and blended automotive fuel for diesel engines. J. curcas seeds yield approach 6-8 MT/ha with 37%
oil. Such yield could produce an equivalent of 2100-2800 litres fuel oil/ha, whose energy is equivalent to 19,800-26,400 kwh/ha (Tomomatsu and Swallow, 2007). Due to its very high saponification value and its ability to burn without emitting smoke, the oil of the seeds is commercially useful (Wiskerke, 2008). Therefore there is need to identify the highest yielding jatropha in Kenya to be developed for commercial use.

1.2 Statement of the problem and justification

Biodiesel as an alternative fuel for diesel engines is becoming increasingly important due to diminishing petroleum reserves and the environmental consequences of exhaust gases from petroleum-fuelled engines. The availability and sustainability of sufficient supplies of less expensive feedstock will be a crucial determinant delivering a competitive biodiesel to the commercial filling stations. Fortunately, inedible vegetable oils, mostly produced by seed-bearing trees and shrubs can provide this much desired alternative. With no competing food uses, this characteristic makes J. curcas a preferred alternative.

The current discussion on bio-energy is dominated heavily by the energy and climate change perspectives. However, what is missing in the bio-energy debate is the discussion of the viability of feedstock production from the perspective of oil quantity and quality for jatropha adapted to different parts in developing countries and in particular Kenya. As controversies arise about the promotion of jatropha biodiesel production between conservators and enthusiasts in other parts of the world, more investments are turning to Africa. There is therefore an urgent need to identify the highest yielding accession of Jatropha curcas to be adopted for biofuel production in Kenya.
1.3 Research hypothesis

There are large variations in biodiesel quality produced from *J. curcas* oil in different parts of Kenya.

1.4 General objective

To evaluate the characteristics of biodiesel produced from *Jatropha curcas* oil in Kenya using trans-esterification process.

1.4.1 Specific objectives

i. To determine the quantity and quality of *Jatropha curcas* crude oil from selected parts in Kenya

ii. To determine the quality of bio-diesel produced and compare the variations relative to the standard requirements for biodiesel production.

1.5 Significance

The study generated data on the Kenyan *Jatropha curcas* with high oil yield and quality. The data obtained can be used to advise farmers and investors on the high yielding jatropha by the ministry of energy and petroleum, ministry of environment, water and natural resource together with the ministry of agriculture, livestock and fisheries in Kenya. This will greatly increase productivity of jatropha cultivation by farmers and also help investors in identifying potential regions to obtain high quality feedstock for biofuel production.
CHAPTER TWO

LITERATURE REVIEW

2.1 Background information

*Jatropha curcas*, belongs to the family of Euphorbiaceae, originating in Latin America widely spread throughout the arid and semi-arid tropical regions of the world. Jatropha is a large genus comprising over 170 species (Heller, 1996). *Jatropha curcas* is a small tree or shrub with smooth grey bark, which exudes a whitish coloured, watery-latex when cut. Normally, it grows between three and five meters in height, but can attain a height of up to eight to ten meters under favourable conditions. It is a drought resistant plant, growing on arid and semi-arid lands (Heller, 1996).

*Jatropha curcas* has large green to pale green leaves with petioles of the flowers ranging between 6-23 mm in length. The flowers are formed in hot seasons. Several crops are formed provided the soil moisture is good and the temperatures are high. In conditions where continuous growth occurs, an imbalance of pistillate or staminate flower production results in a higher number of female flowers. Fruits are produced in the cold season when the shrub is leafless. Each inflorescence yields a bunch of approximately 10 ovoid fruits. Three, bi-valved cocci are formed after seeds mature and the fleshy exocarp dries. The seeds become mature when the capsule changes from green to yellow, after two to four months from fertilisation. The blackish, thin-shelled seeds are oblong and resemble small castor seeds. This plant has various medicinal uses especially in nutraceuticals, pharmaceutical, dermatological and personal care products. The latex of *J. curcas* has anticancer properties due to the presence of an alkaloid known as ‘jatrophone’.
The tender twigs are used for cleaning teeth while the juice of the leaf is used for anthelminthic purposes (Nahar and Ozores-Hampton, 2011). The bark yields a dark blue dye used for colouring cloth, fish nets and lines. Most of the Jatropha species are ornamental except for *J. curcas* and *J. glandulifera* which are oil-yielding species. The seeds of these species contain semi-dry oil which has been found useful for medicinal and veterinary purposes (Gubitz *et al.*, 1999). The oil content is 25-30% in the seeds and 50-60% in the kernel. The jatropha oil contains 21% saturated fatty acids and 79% unsaturated fatty acids. Jatropha oil contains linolenic acid (C18:2) and oleic acid (C18:1) which together account for up to 80% of oil composition. Palmitic (C16:0) and stearic (C18:0) acids are other fatty acids present in this oil (Maundu and Tengnas, 2005).

In Africa, *J. curcas* is considered to be one of the most viable candidates for biodiesel feedstocks mostly due to its adaptability to semi-arid lands. Biodiesel promoters regard this “low productive land” (or often called “marginal” or “waste” land) to be largely available for new agricultural development. After having been introduced to Africa centuries ago, *J. curcas* is now widely observed in semi-arid lands throughout the drier areas of the continent.

In Kenya, it is naturalized in bush lands and along rivers in the western, central and coastal parts of the country in altitudes of 0-1,650 meters above sea level (Maundu and Tengnas, 2005). The planting of Jatropha trees has been taking place in some areas across Africa. For example, around the N’guruman area of Kajiado District in Kenya, the local population has extensively planted Jatropha as a hedge and boundary marker. In Tanzania, Uganda and Madagascar, Jatropha is intercropped with vanilla (*Vanilla*...
plantifolia) to serve as a support for vanilla vines and to provide shade for vanilla leaves. In these and other African countries, the extracted oil from Jatropha seeds has been used for soap making (Maundu and Tengnas, 2005).

In the 1990s, the German Technical Cooperation (GTZ) conducted experiments in Mali on the use of jatropha oil as a renewable fuel for powering diesel engines (Henning, 2002). However, it is only recently that the production of jatropha as a biodiesel feedstock has become widely promoted by private enterprises, non-governmental organizations and overseas development assistance agencies working in Africa, including Kenya. Jatropha production has been promoted for its perceived economic and ecological advantages. From the perspective of private investors, it is a newly available energy crop that is expected to be less expensive to produce when compared to other energy crops such as rapeseed and soybean. This argument is based on availability of low-cost labour and land in Africa. Like other energy crops, jatropha's contribution to mitigation of greenhouse gas (GHG) emissions is strongly emphasized, with the assumption that new regulations and carbon offset markets will provide price premiums for renewable sources of energy. The Clean Development Mechanism (CDM) of the Kyoto Protocol is expected to promote investment in renewable energy supply by both developed and developing countries with potential to produce biofuel feedstock (Tomomatsu and Swallow, 2007). If the acquisition of Certified Emission Reductions (CERs) is assured, the CDM would give additional investment incentives for investors in developed countries who otherwise would not invest in biofuel projects due to the high risk of returns.
Not only private enterprises, but also non-governmental organizations and development agencies are interested in supporting jatropha development in Africa as a means for rural development and poverty alleviation. Jatropha biodiesel production is expected to contribute to the improvement of rural livelihood because the main production location for jatropha is in the semi-arid lands where poverty levels are high and land productivity for agricultural produce is low (Tomomatsu and Swallow, 2007).

2.2 Current status of jatropha production in Kenya

Though jatropha is not indigenous to Kenya, the species seems to have been introduced close to a century ago, judging from the age of the trees growing wildly in the country (Muok and Källbäck, 2008). The history of its introduction however, is not well known. From the natural stands in Kenya, the tendency to spread has not been observed and it is rare to find young trees (Muok and Källbäck, 2008). In Kenya, jatropha is mainly grown in the Rift Valley (Kajiado, Namanga, Nakuru, Naivasha and Marakwet), Nyanza, Central (Thika), Eastern (Kitui and Meru) and the Coast (Malindi) provinces. In East Africa, Tanzania is said to have made the biggest strides in terms of growing the fuel tree on large scale, however, Kenya is said to be well ahead of other African countries in research on the same (Muok and Källbäck, 2008).

Government policy plays an important role in fostering growth of the biodiesel industry. Active government support has been essential in every country where biodiesel and other biofuel industries have been successfully established. Government policy influences the returns that can be generated from different value chains and thus the potential returns to different types of actors. The government has an interest in reintroducing power alcohol
as a motor fuel in its long-term policy to enhance security of supply if it could overcome the problem of competitiveness in the market place (Kenya, 2004). However, the government has taken a cautious approach towards reconsidering support for the biofuels industry, due to the experience of previous policy failures. In Kenya, various stakeholders in biodiesel industries formed the national biodiesel committee in January 2006 under the Ministry of Energy to have a collective voice in promoting policies such as blending mandates, tax mandates and production subsidies (Kituyi, 2006; Kituyi, 2007).

Policy support is a not straightforward issue. Different government policies affect different stages of the value chain for different actors. Tax reductions or exemptions, low-interest loans, and tax holidays to biofuel producers could produce a competitive margin for firms involved in the oil extraction and trans-esterification processes. Meanwhile, only direct subsidies to producers will affect the viability of feedstock production. However, it is likely that direct subsidies will be of much greater benefit to large-scale producers than smallholder farmers (Kojima, 2005). India began its current biodiesel programme, the “National Mission on Biodiesel,” in 2003. The programme focuses primarily on production and processing of feedstock from jatropha and pongamia. The national biodiesel programme encourages states to adopt different combinations of policies to meet targets for increased biodiesel production, including subsidising water and electricity to set up plants, allowing companies to lease government wasteland, and undertaking state-owned jatropha plantations (Mohan, Phillippe and Shiju, 2006). However, the main government support has focused on large-scale production, rather than production by smallholder farmers.
If the Government of Kenya does support the large-scale development of the biodiesel industry, it must consider the likely conflict of interest between local communities and the biodiesel industry concerning the “actual outcome” brought from different production channels in the jatropha biodiesel value chain. The pastoralist community living in the Tana Delta, the large stand most ecologically and biologically diverse wetland in East Africa filed a suit in court to bar two organisations from setting up a Sh24 billion 12,000 hectares sugar project in the area. The pastoralist communities feared that they could lose their homes and that there would be damage to the ecosystem (Machuhi, 2007). The government should analyze the socio-economic impact on local communities of potential land use changes, and base its policy decisions on the need for equitable benefits among different stakeholders. The government must propose a clear policy vision on the direction of jatropha biodiesel industry, whether focusing on the improvement of local livelihood by setting up small-scale processing facilities, or supporting the large-scale production by private enterprises.

2.3 Jatropha curcas as a biofuel plant

The *J. curcas Linnaeus* plant originated from Mexico and was spread to Asia and Africa by Portuguese traders as a hedge plant. *J. curcas* L. belongs to the family Euphorbiaceae, which is renowned of having species that contravene the Geneva conventions on chemical warfare. The genus name jatropha derives from the Greek *jatros* (doctor), *trophe* (food), which implies medicinal uses; hence the plant is traditionally used for medicinal purposes. It is a hardy shrub that can grow on poor soils and areas of low rainfall (from 250 mm a year) hence its being promoted as the ideal plant for small
farmers (Foidl et al., 1996; Sarin et al., 2007; Gressel, 2008). Since Jatropha can grow relatively well in marginal areas compared to other traditional crops, it may help to reclaim degraded land and protecting the soil from soil erosion. The trees are easy to establish (from seeds or cuttings), grow relatively quickly (producing seed after their second year) and are hardy to drought. On average, each mature tree produces about four kilograms of seed per year when cultivated under optimal conditions. It has a long productive period of around 30 - 50 years (Banapurmath et al., 2008; Tamalampundi et al., 2008). The proximate analysis of jatropha seeds revealed that the percentage of crude protein, crude fat and moisture were 24.60, 47.25 and 5.54% respectively (Akintayo, 2004). The seeds can be transported without deterioration and at low cost due to its high specific weight. The seeds of the Jatropha contain 30 - 40% oil that can be easily expressed for processing (trans-esterification) and refinement to produce biodiesel (Gubitz et al., 1999; Akintayo, 2004; Mahanta et al., 2008). *Jatropha curcas* gives higher oil yield per hectare than peanuts, sunflower, soya, maize or cotton when grown under optimum conditions. The processed oil can be used directly in diesel engines after minor modifications or after blending with conventional diesel. The fact that the oil of *J. curcas* cannot be used for nutritional purposes without detoxification makes its use as an energy source for fuel production very attractive. The by-products of the biodiesel processing plant are nitrogen-rich press cake and glycerol, which are said to have good commercial value as fertiliser and as a base for soap and cosmetics, respectively.

*Jatropha curcas* is traditionally used for medicines and as hedges to protect fields and gardens since animals do not eat it (Joubert et al., 1984; Mampane et al., 1987; Gubitz et al., 1999; Staubamann, et al., 1999). The leaves, roots and bark also have potential for
numerous other industrial and pharmaceutical uses. A number of enzymes such as protease, lipase and esterase with good properties for use in biotechnology have also been extracted and purified from *J. curcas* L. (Nath *et al.*, 1991; Staubamann *et al.*, 1999). These features have generated a great interest in the jatropha plant which is now becoming a cash crop in South and Central America, Europe, Africa and Asia. The positive claims on *J. curcas* are numerous, but only a few of them can be scientifically sustained. The knowledge available on the genetics of the plant and experience with breeding programmes are limited (Jongschaap *et al.*, 2007). However due to several claims regarding its special characteristics, jatropha is seen as a promising biofuel plant (Van Eijck, 2007).

In addition, jatropha is seen as a promising biofuel plant because the plant itself and the oil are non-edible. This means that jatropha plants are less likely to be eaten by animals such as grazing cattle. The third reason why Jatropha is seen as promising is because it has many rural applications (Henning, 2002). The toxicity of *J. curcas* is based on several components such as phorbol esters, curcains, trypsin inhibitors and others that are present in considerable amounts in all plant components which make complete detoxification a difficulty and complicated process. The best extraction procedures available for the removal of phorbol esters remove about half, which is unacceptable toxicologically in accessions with high initial content (Makkar *et al.*, 1997; Haas and Mittelbach, 2000; Martinez *et al.*, 2006).

Straight jatropha oil can be used in lamps and cooking stoves or as a substitute fuel in modified diesel engines for example in tractors used for farming which will be very
useful to many farming communities in Kenya. When SJO is blended with regular diesel up to 10-20% V/V, the mixture can be used as fuel in unmodified diesel engines. Furthermore, soap can be produced from SJO, which has medicinal characteristics (Wiskerke, 2008). When pressing the seeds for oil, the seedcake that remains as a by-product can be used as briquette, fertilizer or input in a biogas plant (Heller, 1996). There are now many concerns in the world regarding the cultivation of the *J. curcas* tree both at small-scale and large-scale without due consideration of its impact on ecology, food production and the environment. The tree has an invasive potential through seed dispersal. Due to its perceived benefits, the growing of the *J. curcas* is shifting from small-scale farmers to tight controlled corporate production either on large plantations or through stringent contract production in India, Burma, Saudi Arabia, Malaysia, Indonesia, Philippines, China, Ghana, South Africa, Senegal, Nigeria, Tanzania, Ethiopia, Zambia and Zimbabwe among other countries. Introducing an alien species at large scale in the environment, even if it can potentially contribute to rural employment and poverty alleviation, needs serious consideration. The claimed tolerance of *J. curcas* to pest sand diseases on few dispersed trees might not apply in general to trees in plantations. Indeed Jatropha can grow in the semi-arid lands but may be without any commercial yield being achieved. There is increasing evidence that seed yields are sensitive to soil fertility and moisture availability. According to Foidl *et al.* (1996) the predictions of productivity seem to ignore the results of plantations from the 1990s, most of which are abandoned now for reasons of lower productivity and or higher labour costs than expected. There is still lack of knowledge on its potential yield under sub-optimal and marginal conditions making it difficult to predict yields from planned plantations under sub-optimal growth
conditions, where *J. curcas* is supposed to prove its value. Some authorities predict yields ranging from 0.6 – 15 tonnes seed per hectare per year under proper conditions of crop establishment, water and fertility levels. Depending on crop growth conditions, such as water, soil fertility and absence of disease, maximum yields of 7.8 tonnes seed per hectare are predicted for mature stands. The seed yield and seed oil yield varies widely which is logic for a crop that grows under many different conditions. Genetic and environmental factors have a significant on oil yield production factors. *J. curcas* is still a wild species and genetic identification of provenances and testing them in different locations and conditions still need to be done.

There is also still a dearth of research about the influence of various cultivation-related factors and their interactions and influence on seed yield. Projections of seed yield and oil yield on plantations in many websites lack a sound scientific basis with wide variations and do not give description of conditions under which data were collected (Openshaw, 2000). It may not be true that jatropha oil production requires minimum amounts of labour because labour is required to prepare the land, set-up nurseries, plant, irrigate, fertilise, prune, harvest and process the seeds ready for the market, particularly in the early years. It is expected that labour for maintenance and harvest should increase to substantial levels in subsequent years. Otherwise minimum labour is only required only if *J. curcas* is grown for combating desertification and preventing soil erosion. The global expansion of biofuels production will have serious ramifications for Africa, which has large landmass and favourable climate for growing energy crops. There is need for proper policies and mechanisms to regulate the sector to ensure that biofuels such as jatropha are not given too much priority at the expense of other important values for nature,
environment and society. Of particular concern is the competition for land, water and the
displacement of land for the cultivation of food and other crops. The production of energy
crops such as jatropha in Africa might be so attractive in terms of income that may induce
the diversion of resources away from food production for biofuels thereby threatening
food security. An influx of large investors could also lead to undesirable competition with
food crops.

Farmers could be induced to become out growers of large buyers, converting too much
prime crop land to jatropha cultivation or worse still induced to sell their land to large
investors. There is still a significant amount of research that needs to be done on jatropha
before it could become a dominant and sustainable source of biodiesel. The actual
breeding and development of the genetic resources of jatropha are quite at an early stage.
There is need to know far more about the different genotypes and varieties of jatropha
around the world, and whether there is a large amount of genetic variation that can be
used to develop Jatropha crops for different geographical locations. The genus jatropha
contains approximately 170 known species (Katemo and Gray, 2007). The direct usage
of this vegetable oil (triglyceric esters) as biodiesel is possible but unsatisfactory for long
term usages in today’s direct and indirect diesel engines (Ma and Hanna, 1999;
Ranganathan et al., 2008). This is because they have high viscosity, are contaminated by
acid, and form gum due to oxidation and polymerisation of free fatty acids during storage
and combustion, deposit of carbon on engines and thickening of lubricating oil.
Therefore, vegetable oils are processed so as to acquire viscosity and volatility
characteristics similar to fossil fuels (Agarwal, et al., 2007).
2.4 Uses of jatropha oil

Jatropha is an ornamental plant naturalised in many tropical areas. The roots, stems, leaves seeds and fruits of the plant have been widely used in traditional folk medicine in many parts of West Africa. The seeds of *J. curcas* have been used as a purgative, antihelminthic and abortifacient as well as for treating ascites, gout, paralysis and skin diseases. The seed oil of the plant has been used as an ingredient in the treatment of rheumatic conditions, itch and parasitic skin diseases, and in the treatment of fever, jaundice and gonorrhea, as a diuretic agent, and a mouth-wash. The leaf has been used as a haemostatic agent and the bark as a fish poison. In certain African countries people are accustomed to chewing these seeds when in need of a laxative. *J. curcas* seeds have been found to be highly effective against *Strongyloides papillosus* infection in goats (Adam and Magzoub, in press). It has also been suggested that *J. curcas* seeds could be a useful chemotherapeutic agent provided that it is active at a non-lethal dose (Adam, 1974). This may be because of its reported antihelminthic activity.

The opportunity for local populations to maximize benefits from jatropha is to engage not only in jatropha production but also in oil extraction. Even if trans-esterification is not realistic, locally extracted oil can be directly used in diesel engines or as a kerosene substitute for lamps and stoves (Heller, 1996). The direct use of pure jatropha oil for lister-type diesel engines has been experimented by GTZ in Mali (Henning, 2002). The direct use of oil in these engines is limited to areas with warm climates due to the viscosity of jatropha oil (Benge, 2006).
Experiments are also under way to use jatropha oil as a substitute for kerosene in lamps and stoves. Jatropha oil is much less expensive than kerosene so its use could contribute to savings for local communities and poor urban households. Constraints on the promotion of jatropha oil for lighting and stoves are discussed by van Eijck (2007) for the case of Tanzania. Using jatropha oil for lighting and cooking requires different equipment than that used for kerosene. Lamps need to be modified to account for the high viscosity and low absorbance of jatropha oil in the wick. Special lamps and stoves designed for jatropha oil have been developed and tested by NGOs in Tanzania. However, there is not yet a good network to widely distribute that equipment. The successful promotion of jatropha oil for cooking depends on the availability and affordability of other energy sources (e.g. fuelwood, charcoal, liquid natural gas, etc.) in the local context. Early project developers are aware of the difficulty of introducing new sources of energy in communities where kerosene has been used for a long time and families may be slow to adopt new fuels and equipment (Mbola, 2004). Currently, the most promising and well developed uses of jatropha are for soap and candle making (Tigere et al., 2007). Soap production with jatropha oil has been promoted in Mali, Tanzania and Madagascar where it has gained recognition in the market as an anti-septic natural soap. However, the market for jatropha soap may not expand much beyond its current size due to the high price compared to ordinary soaps (van Eijck, 2007).

Currently three different modes of jatropha production are taking place in Kenya: monoculture mixed intercropping, hedges and intercropping with vanilla. In Makueni District where jatropha production has been introduced by non-governmental organizations, some farmers are converting their farms into jatropha plantations, although
they intercrop jatropha with other food crops for the first year when jatropha is relatively small. Some farmers with limited landholdings have decided to experiment with growing jatropha as a hedge. However, the majority of farmers in the area are observing their neighbours’ production of this new crop to see how profitable it will be. The intercropping of jatropha with vanilla was started in the coastal zone of Kenya since 2005. At this moment, there is neither biodiesel production nor purchase agreements between farmers and buyers.

Different yields of jatropha are reported and estimated by different authors. There has been neither a long history of production nor systematic data collected in different production conditions with varying climate, soil fertility, landform, altitude, water and fertilizer inputs etc. Yield varies significantly depending on the water input, which determines the number of fruiting period per year, which can vary from one to three. From the early experience of jatropha production by research institutes, private enterprises and local farmers in Maharastra state, Rao (2006) estimates that the average yield of jatropha seeds in dry lands is unlikely to exceed 400 kilograms per acre per year. Prajapati and Prajapati (2005) estimated jatropha yields in rain fed and irrigated conditions in India. After 5 years, the production per tree ranged from 1.2 kilogams under rain fed conditions to 3.2 kilograms under irrigated conditions. The yield in rain fed conditions is around 40% as high as under irrigation, implying that jatropha can be grown in semi-arid lands but requires certain level of rainfall to produce high yields. In other words, the plant can survive but not give high yields under conditions of stress (Kureel, 2006). In Mali where jatropha was planted as a hedge by GTZ in the 1990s, the
production of seeds was calculated to be about 0.8 kilograms per meter of hedge (Henning, 2002).

In Kenya, there currently is experimentation with other feedstocks for biodiesel production. The economic case for these crops may be stronger than for jatropha. For example, the production of canola as a biodiesel feedstock is being undertaken by a private enterprise in Nyeri District, where it appears to be more promising than jatropha due to its value as both high-quality edible oil and potential biofuel source, and the high value of its by-product, edible seedcake which is used for animal feed.

2.5 Biodiesel

Although biofuels are often considered 'new fuels' they have in fact been in use since the earliest internal combustion engines were developed but details on the first uses (until the early 1950s) are often unclear or presented inconsistently in the literature. One of the first prototypes of the diesel engine invented by Rudolf Diesel in 1892 was designed to run on vegetable oil, and several of Henry Ford’s first internal combustion engines in 1908 were designed to run on bioethanol rather than petrol (Mathot, 1921; Knothe, 2001; Fitzgerald, 2007). The rapid growing trend for the usage of biofuels, however, waned during the 1920s when an engine capable of utilising petroleum, a residue of fossil fuel was developed. The petroleum industry spearheaded by industrialists such as Rockefellers, W. R. Hust and A. Mellon in 1930s launched campaigns to discredit the use of hemp (that is Marijuana Tax Act of 1937). In 1991, the first industrial production plant for RME production was inaugurated in Donau, Austria. During the World War II, biodiesel again came into prominence particularly among the military both in Germany and in the United
States. However, biodiesel popularity waned once again after the war due to desire for mass-produced vehicles fuelled by petroleum when the Western European nations and the United States became prosperous. The oil crisis of the 1970s and resultant high prices and the growing awareness of the environmental impact of the use of fossil diesel encouraged many countries to commence research into the development of alternative fuels. Various teams in Austria, Germany, New Zealand and South Africa soon directed their research efforts to production of biodiesel. Brazil pioneered large scale production of bioethanol during the Middle Eastern oil embargo of the 1970s (Schwab et al., 1988; Pousa et al., 2007). Beginning in 1980, there was considerable discussion regarding use of vegetable oil as a fuel. Additional work was carried out in the 1980s on biodiesel development in South Africa in response to economic sanctions (Knothe, 2001) and in the early 1990s farmers in Austria started cooperatives to produce and use biodiesel commercially (Knothe et al., 2005). Rapeseed oil methyl esters was produced and its feasibility as a diesel fuel was first tested at Graz University (Mittelbach et al., 1999). Documentation of the rapid growth of this industry started in 1996. In 2008 ASTM published biodiesel specification standards (www.astm.org). Today, biodiesel fuels have been in commercial use in many nations including Austria, Czech Republic, Germany, France, Italy, Spain and U.S.A. Activities in biodiesel production and utilization are taking place in every corner of the globe.

Biofuels are considered in part, a solution to such issues as sustainable development, energy security and a reduction of greenhouse gas emissions. Biodiesel, an environmental friendly diesel fuel similar to petro-diesel in combustion properties, has received considerable attention in the recent past worldwide. Biodiesel is a methyl or ethyl ester of
fatty acid made from renewable biological resources such as vegetable oils (both edible and non-edible), recycled waste vegetable oil and animal fats (Demirbas, 2000; Kinney and Clemente, 2005; Wilson et al., 2005). The use of vegetable oils as alternative fuels has been around since 1900 when the inventor of the diesel engine Rudolph Diesel first tested peanut oil in his compression ignition engine (Shay, 1993). However, due to cheap petroleum products such non-conventional fuels never took off until recently. Biodiesel derived from surplus edible oils like soybean, sunflower and rapeseed oil is already being used in USA and Europe to reduce air pollution, to reduce dependence on depleting fossil fuel localised in specific regions of the world and increases in crude oil prices (Foidl et al., 1996; Ma and Hanna, 1999; Openshaw, 2000; Agarwal, 2007; Sarin et al., 2007; Berchmans and Hirata, 2008; Ranganathan et al., 2008). In Asia and Africa, which are mostly net importers of vegetable oil, *Jatropha curcas* has been recognised as new energy crop for the countries to grow their own renewable energy source with many promising benefits. With the growing interest in biofuels worldwide, there is need for national governments in Africa to develop mechanisms for harnessing the potential of the fast growing industry and benefit from the growing international trade in biofuels. If Africa takes the lead in the production of biofuel, particularly from jatropha, the continent’s efforts in this endeavour will position it as an exporter of biodiesel, thus increasing its economic and political leverage in the global society. Many multinational companies, particularly Scandinavian, Chinese, European and Indian ones are scrambling for African land for Jatropha plantations. It is also reported that wireless communication giants Ericsson, GSMA and MTN are investing in using biofuel from Jatropha and other oils to
power cellular network base stations in the developing world for the untapped market of the potential mobile users (Katembo and Gray, 2007).

Biodiesel is a liquid substitute for petroleum-based diesel fuel, formally known as either methyl-ester or ethyl-ester. It is derived from naturally occurring vegetable oils or animal fats that have been chemically modified (esterified) to run in a diesel engine. Biodiesel’s advantages compared to petroleum diesel include its renewable nature, superior emissions properties, and support for domestic agriculture. Vegetable oil can be derived from a wide variety of oil-bearing plants such as castor, coconut, croton, Jatropha, rapeseed (canola), and sunflower. Waste vegetable oil can also be used for biodiesel. Levels of technological development for biofuels are defined as first, second and third generation (FAO, 2010). First generation biofuels are the fuels now in common use, derived mainly from food crops by utilizing conventional technology. The important biofuel crops are maize, sugar cane and sugar beet for the extraction of sugars to produce bioethanol, and soybean, rapeseed and oil palm for the extraction of oil to produce biodiesel. Technologies for the second and third generation biofuels remain under development. They offer the prospects of producing biofuels from non-food sources such as the first growing trees, grasses and carbon-rich waste materials. These future technologies will also have the capability of converting algae and bacteria into oils that can replace petroleum fuels.

Biodiesel as an alternative fuel for diesel engines is becoming increasingly important due to diminishing petroleum reserves and the environmental consequences of exhaust gases from petroleum-fuelled engines. Biodiesel, which is made from renewable resources,
consists of simple alkyl esters of fatty acids. As a future prospective fuel, biodiesel has to compete economically with petroleum diesel fuels. One way of reducing the biodiesel production costs is to use the less expensive feedstock containing fatty acids such as inedible oils, animal fats, waste food oil and by-products of the refining vegetables oils (Veljkovic´ et al., 2006). The availability and sustainability of sufficient supplies of less expensive feedstock will be a crucial determinant delivering a competitive biodiesel to the commercial filling stations.

Studies from India show favourable energy balances for the physic nut or Jatropha when used as feedstock for biodiesel production (Jain and Sharma, 2010). Besides being unfit for human consumption, Jatropha appears to have the necessary qualities of becoming the major vegetable oil crop for economically and environmentally sustainable biodiesel production in tropical Africa. Each hectare can produce an average of 500 gallons (1900 litres) of biodiesel per year from its nuts as well as more than 7500 lbs (3400 kilograms) of waste biomass. For biodiesel, jatropha yields more than four times as much fuel per hectare as soybean and more than ten times that of corn (Jain and Sharma, 2010).

2.5.1 Advantages of Biodiesel

2.5.1.1 Lower emissions

Besides not being refined from crude oil, biodiesel offers other attractive characteristics, such as a significantly lower emission of carbon monoxide, CO (46.7 %, carbon dioxide, CO₂, (78%), sulphur dioxide, SO₂ and hydrocarbons, HC (45.2%). It also eliminates the cloud of dense, black smoke normally associated with diesel vehicles and other
particulate matter (PM) emissions (66.7%) that cause respiratory damage to a level in line with the Kyoto Protocol Agreement (Schumacher et al., 2001).

2.5.1.2 Biodegradability

Biodiesel is reported to be highly biodegradable in freshwater as well as soil environments. 90–98% of biodiesel is mineralized in 21–28 days under aerobic as well as anaerobic conditions in comparison to 50% and 56% by diesel fuel and gasoline respectively (Pasqualino et al., 2006). European tests of rape seed oil-based biodiesel indicate that it is 99.6% biodegradable within 21 days (Korbitz, 1999). Thus within one month of being spilled into the environment, biodiesel should be completely decomposed. This makes biodiesel a good alternative fuel for use in environmentally sensitive areas where fuel leakages and spills would be particularly harmful such as wetland areas and watersheds which supply drinking water.

2.5.1.3 Favourable fuel properties

Biodiesels have high cetane number, high flash point and acceptable level of sulphur content which makes it very attractive as an alternative fuel (Graboski et al., 1998). Reported work by Korbitz (1999) shows that the cetane number of biodiesel fuels is higher than fossil diesel which is considered to be significantly advantageous in terms of engine performance. The flash point of biodiesel fuels is twice as much as that of fossil diesel. Therefore, biodiesel is much safer to store, handle and use than the conventional diesel fuel. Biodiesel fuels have been praised as being sulphur-free and may contain only traces of sulphur emanated from the acidic catalyst used.
2.5.1.4 Compatibility

Biodiesel is virtually compatible with commercial diesel engines and practically no engine modifications are required (Patzek, 2004). Biodiesel can also be blended at any level with petroleum diesel to create a biodiesel blend. When blended with fossil diesel, it shows positive synergic effect of biodegradation by means of co-metabolism. For example, the time taken to reach 50% biodegradation of fossil diesel is reduced from 28 to 22 days in 5% biodiesel mixture (Boopathy, 2004).

2.5.1.5 Economic benefit

With oil prices projected to remain well above US $70 per barrel for the foreseeable future (IEA, 2007), biodiesel production is expected to remain profitable and grow dramatically. Farmers that produce highly rated energy crops such as Jatropha for the production of biodiesel stand a chance of improving their income level by providing market outlets for farmers and generate rural employment. The by-product of trans-esterification reaction, glycerol, when purified can be used in its traditional application (pharmaceutical, cosmetics and food industries). In addition, the obtained glycerol can be used in recently developed applications in the fields of animal feed, carbon feedstock in fermentations, polymers, surfactants and lubricants (Claude, 1999). Biodiesel, thus, increases the contribution of agriculture to exports and economic growth. It will also generate new industries which will create new jobs and new markets for the majority of unemployed youth (Arndt *et al.*, 2007).
2.5.2 Disadvantages of Biodiesel

2.5.2.1 NO\textsubscript{x} emissions

The temperature within the cylinders of a vehicle fuelled with biodiesel would increase due to the enhanced combustion as a result of high oxygen content of biodiesel. This increase in temperature stimulates the production of NO\textsubscript{x} from the reaction with nitrogen in the air, which results in a small increase in NO\textsubscript{x} emission compared to those produced from conventional diesel fuel (Smokers and Smit, 2004).

2.5.2.2 Short shelf-life

Biodiesel chemically is fatty acid methyl ester if alcohol used during trans-esterification is methanol or fatty acid ethyl ester in case of ethanol. These ester molecules are susceptible to hydrolytic and oxidization reactions resulting in the formation of polymers. This makes the biodiesel unstable on storage and hence cannot sit on the shelf for long time as it develops mould when it gets old (Sarin et al., 2007).

2.5.2.3 Competition with food crops

Biodiesel can be made from a wide variety of feedstock including some of which are used as food. When a food crop is used to create biodiesel it is possible to create competition between food in poor countries and biodiesel fuel in rich countries. For example a rich country can go and buy all the palm nuts, corn, etc in Ghana, a poor country, and use that to make biodiesel. By doing this the rich country takes away a major form of food and nutrition that a lot of people in that country depend on. On the other side farmers may stop planting food crops and rather plant crops that can be used to make biodiesel because they can get more money for that kind of crop.
2.5.2.4 High production cost

The total cost of the biodiesel fuel production based on this process is not sufficiently competitive as compared to the cost of production of diesel oil from petroleum. A process model was prepared by Haas et al. (2006) to estimate biodiesel production costs and this revealed that taking all the factors into account viz. raw material (vegetable oil, methanol, and catalysts), utilities (electricity, etc.), labour, supplies, general works and depreciation, the cost of biodiesel was estimated to be US $0.561 l-1 as compared to US $0.35 for normal diesel. Currently, the cost of biodiesel stands at 3.83 dollars per gallon which is 19.6% higher compared to that of petro-diesel ($3.07) (Clean Cities Alternative Fuel Price Report, January 2010).

2.6 Biodiesel production process and technology

Common feedstock used in biodiesel production includes recycled vegetable oil, "virgin" vegetable oil, and tallow. Recycled oil is processed to remove impurities from cooking, storage, and handling, such as dirt, charred food, and water. Virgin oils are refined, but not to a food-grade level. Degumming to remove phospholipids and other plant matter is common, though refinement processes vary. Regardless of the feedstock, water is removed as its presence during base-catalyzed trans-esterification causes the triglycerides to hydrolyze, giving salts of the fatty acids instead of producing biodiesel. Animal and plant fats and oils are composed of triglycerides, which are esters containing three free fatty acids and the trihydric alcohol, glycerol. In the trans-esterification process, the alcohol is deprotonated with a base to make it a stronger nucleophile. Commonly, ethanol or methanol is used. As can be seen, the reaction has no other inputs than the
triglyceride and the alcohol. Under normal conditions, this reaction will proceed either exceedingly slowly or not at all, so heat, as well as a catalyst is used to speed the reaction. It is important to note that the catalyst is not consumed by the trans-esterification reaction, thus it is not a reactant. Common catalysts for trans-esterification include sodium hydroxide, potassium hydroxide, and sodium methoxide.

Almost all biodiesel is produced from virgin vegetable oils using the base-catalyzed technique as it is the most economical process for treating virgin vegetable oils, requiring only low temperatures and pressures and producing over 98% conversion yield (provided the starting oil is low in moisture and free fatty acids). However, biodiesel produced from other sources or by other methods may require acid catalysis, which is much slower.

There are two types of biodiesel processes: batch and continuous. Both processes rely on the basic chemical reaction described above, although batch reactors are generally used for smaller levels of production, while continuous reactors are employed for larger commercial plants (Sharma and Agarwal, 2007). The two main by-products of biodiesel manufacturing; glycerol and seedcake have value that helps to reduce the overall costs of production. Glycerol can be processed into soap, burned for energy or composted. However, before glycerol can be used for soap or other industrial processes, the impurities introduced during the biodiesel manufacturing process must be separated from the glycerin through a refinement process. Burning glycerol for energy also poses environmental risks if not done at high enough temperatures due to the release of a toxic air pollutant called acrolein (Shay, 2007).
2.6.1 Trans-esterification

Trans-esterification is the most common method of converting crude oil into biodiesel that can be used directly or as blends with diesel in diesel engines. It is also called alcoholysis, is the reaction of a fat or oil (triglyceride) with an alcohol to form fatty acid alkyl esters (valuable intermediates in oleo chemistry), methyl and ethyl esters which are excellent substitutes for biodiesel. This process is similar to hydrolysis, except that an alcohol is used instead of water. This process has been widely used to reduce the viscosity of triglycerides (Barnwal and Sharma, 2005). A catalyst is usually used to speed up the reaction that may be basic, acidic or enzymatic in nature. Trans-esterification is therefore a method of transforming an ester into another when a vegetable oil is reacted with methanol in the presence of a catalyst to give methyl esters, biodiesel and an amount of glycerine. The factors that affect the trans-esterification reactions include reaction temperature, ratio of alcohol to vegetable oil, catalyst, mixing intensity and purity of reactants. The trans-esterification process is the reaction of a tri-glyceride with an alcohol to form esters and glycerol. The alcohol reacts with the fatty acids to form the mono-alkyl esters or biodiesel and crude glycerol (Sharma and Agarwal, 2007). The stoichiometry of trans-esterification reaction requires three mol of alcohol per mol of triglyceride to yield three mol fatty ester and one mol glycerol.
Trans-esterification as an industrial process is usually carried out by heating an excess of the alcohol with vegetable oils under different reaction conditions in the presence of an inorganic catalyst. The reaction is reversible and therefore excess alcohol is used to shift the equilibrium to the products side. The alcohols that can be used in the trans-esterification process are methanol, ethanol, propanol, butanol and amyl alcohol, with methanol and alcohol being frequently used. The reactions are often catalysed by an acid, a base or enzyme to improve the reaction rate and yield. Alkali-catalysed trans-esterification is much faster than acid-catalysed trans-esterification and is most often used commercially (Ma and Hanna, 1999; Agarwal and Agarwal, 2007; Ranganathan et al., 2008). The alkalis which are used include sodium hydroxide, potassium hydroxide, and carbonates. Sulphuric acid, sulfonic acids, and hydrochloric acids are the usual acid catalysts. After trans-esterification of triglycerides, the products are a mixture of esters, glycerol, alcohol, catalyst and tri-, di- and monoglycerides which are then separated in the downstream (Freedman et al., 1986; Ma and Hanna, 1999; Demirbas, 2005). The process of trans-esterification brings about drastic change in viscosity of the vegetable oil. The high viscosity component, glycerol, is removed and hence the product has low
viscosity like the fossil fuels. The biodiesel produced is totally miscible with mineral diesel in any proportion. Flash point of the biodiesel is lowered after trans-esterification and the cetane number is improved. The yield of biodiesel in the process of trans-esterification is affected by several process parameters which include; presence of moisture and free fatty acids (FFA), reaction time, reaction temperature, catalyst and molar ratio of alcohol and oil.

There are two type of trans-esterification, when the amount of free fatty acids (FFA) contents in the oil is more than 1%, acid is used to catalyze the trans-esterification reaction. This is known as acid catalyzed esterification reaction, used to reduce FFA contents and increase the yield of alkyl esters (Sharma and Agarwal, 2007). When a base is used to catalyze the trans-esterification reaction, it is known as base catalyst trans-esterification reaction. It is used when the amount of FFA contents are less than 1%. In this step, conversion of triglycerides into alkyl esters and glycerol occur. The lighter layer (biodiesel) is separated from heavier glycerol phase by separation. The lighter biodiesel is removed, washed with water, dried over anhydrous sodium sulphate and can be used directly as engine fuel in diesel engines (Sharma and Agarwal, 2007).

2.6.2 Supercritical process

An alternative, catalyst-free method for trans-esterification uses supercritical methanol at high temperatures and pressures in a continuous process. In the supercritical state, the oil and methanol are in a single phase, and reaction occurs spontaneously and rapidly (Bunkyakiat et al., 2006). The process can tolerate water in the feedstock, free fatty acids are converted to methyl esters instead of soap, so a wide variety of feedstocks can be
used. Also the catalyst removal step is eliminated (Vera et al., 2005). High temperatures and pressures are required, but energy costs of production are similar or less than catalytic production routes (Kusdiana et al., 2007).

2.6.3 Ultra- and high-shear in-line and batch reactors

Ultra- and High Shear in-line or batch reactors allow production of biodiesel continuously, semi-continuously, and in batch-mode. This drastically reduces production time and increases production volume. The reaction takes place in the high-energetic shear zone of the Ultra- and High Shear mixer by reducing the droplet size of the immiscible liquids such as oil or fats and methanol. Therefore, the smaller the droplet size the larger the surface area the faster the catalyst can react.

2.6.4 Ultrasonic reactor method

In the ultrasonic reactor method, the ultrasonic waves cause the reaction mixture to produce and collapse bubbles constantly. This cavitation provides simultaneously the mixing and heating required to carry out the trans-esterification process. Thus using an ultrasonic reactor for biodiesel production drastically reduces the reaction time, reaction temperatures, and energy input. Hence the process of trans-esterification can run inline rather than using the time consuming batch processing. Industrial scale ultrasonic devices allow for the industrial scale processing of several thousand barrels per day.

2.6.5 Lipase-catalyzed method

Large amounts of research have focused recently on the use of enzymes as a catalyst for the trans-esterification. Researchers have found that very good yields could be obtained
from crude and used oils using lipases. The use of lipases makes the reaction less sensitive to high free fatty acid content, which is a problem with the standard biodiesel process. One problem with the lipase reaction is that methanol cannot be used because it inactivates the lipase catalyst after one batch. However, if methyl acetate is used instead of methanol, the lipase is not in-activated and can be used for several batches, making the lipase system much more cost effective (Du et al., 2004).

2.6.6 Volatile fatty acids from anaerobic digestion of waste streams

Lipids have been drawing considerable attention as a substrate for biodiesel production owing to its sustainability, non-toxicity and energy efficient properties. However, due to cost reasons, attention must be focused on the non-edible sources of lipids, in particular oleaginous microorganisms. Such microbes have the ability to assimilate the carbon sources from a medium and convert the carbon into lipid storage materials. The lipids accumulated by these oleaginous cells can then be trans-esterified to form biodiesel.

2.7 Factors affecting trans-esterification

The main factors affecting trans-esterification are the alcohol to oil molar ratio, catalyst type/concentration, reaction temperature and reaction time. The methanol to oil ratio needs to be higher than stoichiometric ratio to drive the equilibrium to a maximum ester yields.

2.7.1 Effect of alcohol-to-oil molar ratio

One variable that greatly affects the yield of ester in the trans-esterification reaction is the molar ratio of alcohol to triglyceride. The stoichiometric ratio for trans-esterification
requires three moles of alcohol and one mole of triglyceride to yield three moles of fatty acid alkyl esters and one mole of glycerol (van Gerpen, 2004). However, transesterification is an equilibrium reaction in which a large excess of alcohol is required to drive the reaction to the product side.

The molar ratio is associated with the type of vegetable oil used. Meuly in 1944 stated that the practical range of molar ratio was from 3.3 to 5.25: 1 methanol to vegetable oil. The ratio of 4.8: 1 to 34: 1 had been used in some examples, with a yield range of 21-98% depending upon the type and quality of the oil and also the catalyst employed. For instance, Freedman et al. (1984) studied the effect of molar ratio from 1:1 to 6:1 on ester conversion with vegetables and concluded that soybean, sunflower, peanut and cotton seed oils behaved similarly and achieved highest conversion (93-98%) at a 6:1 molar ratio. For the trans-esterification reaction, Sharma and Singh (2007) advocated for 8:1 molar ratio during acidic esterification so as to reduce the acid value below 2 mg KOH/g i.e. 1.0% FFA. When a large amount of free fatty acid was present in the oil, a molar ratio as high as 15:1 was needed under acid catalysis according to Sprules and Price (1950). Nye and Southwell in 1983 in methanolysis of rapeseed oil using 1% NaOH found that the molar ratio of 6:1 of methanol to oil gave the best conversion. Excess alcohol to vegetable oil molar ratio interferes with the separation of glycerol due to increase in solubility.

**2.7.2 Effect of catalyst type**

A very large number of potentially useful catalysts have been investigated as a mean to enhance the reaction rate. Without catalysts, some degree of rearrangement can be obtained but only under extreme conditions of temperature, pressure and time leading to
undesirable effects such as isomerisation, polymerization and decomposition. Catalysts are classified as homogeneous (alkali - NaOH, KOH; acid – H₂SO₄ and alkali-alcoholic - MeOH) or heterogeneous (CaO, MgO, BaO and ZnO/Al₂O₃; alkaline metal oxides supported on zeolite; ion exchange resin). Potassium hydroxide was commonly used as catalyst for the trans-esterification of oils such as *Jatropha curcas*; used frying oil and soybean used frying oil (Foidl, *et al*., 1996). When rice bran oil was used as feedstock, sulphuric acid was used as catalyst (Zullaikah *et al*., 2005). Sodium hydroxide was also chosen to catalyse the trans-esterification of rubber seed oil because it is cheaper (Ramadhas, *et al*., 2005). Different homogeneous catalysts were used to transesterify sunflower oil. Vicente, *et al*., (2005) pointed out that near 100% biodiesel yields were only obtained with sodium methoxide catalyst.

Methanolsysis of soybean oil, in the presence of 1 mol% of H₂SO₄, with an alcohol/oil molar ratio of 30:1 at 65°C, takes 50 hr to reach complete conversion of the vegetable oil (> 99%). Zhang *et al*., (2003) obtained a 97% oil conversion to FAME within 240 min, using a 50:1 molar ratio of methanol to oil and a 0.14:1 weight ratio of sulphuric acid to oil at 80°C. However, this process gives rise to problems linked with the corrosive action of the liquid acid catalyst and to the high quantity of obtained by-products (Loreto *et al*., 2005). According to Lotero *et al*., (2006), the homogeneous alkaline catalysts enable a faster reaction at moderately low temperature and pressure, high conversion rate at low catalyst concentration and are relatively cheap, though, their performance is adversely affected by moisture and soap formation in the presence of high free fatty acids in the seed oil feedstock reducing yield. The homogenous acid catalyst on the other hand can be used even if the seed oil feedstock has higher free fatty acid contents. However, it
requires higher temperatures (373–473K) and higher methanol/oil molar ratio (20–35:1) and also poses environmental problem due to its corrosive and polluting nature.

Investigation into the use and the development of the heterogeneous catalyst process which is expected to be an effective biodiesel production process with low cost and minimal environmental impact is still on-going because of the possibility of simplifying the production and purification processes under mild conditions. For example, the transesterification reaction of soybean oil with ETS-10 zeolite has been studied; conversion in excess of 90% was achieved at a temperature of 1000°C (Suppes et al., 2004). It has also been reported that the conversion to methyl ester reaches 87% with the potassium-loaded alumina catalyst, when a mixture with a molar ratio of methanol to oil of 15:1 is refluxed for a reaction time of seven hours (Xie et al., 2006). Besides these, there have been several other reports on heterogeneous catalysts (Gryglewicz, 1999; Suppes et al., 2001; Kim et al., 2004; Jitputti et al., 2006).

Attempts have been made to use alkaline-earth metal compounds in the transesterification of rapeseed oil for the production of FAME (Gryglewicz, 1999). The catalytic activity of magnesium oxide, calcium hydroxide, calcium oxide, calcium methoxide, barium hydroxide, and for comparison, sodium hydroxide during the trans-esterification of rapeseed oil was investigated by the author. Sodium hydroxide exhibited the highest catalytic activity in this process. Barium hydroxide was slightly less active with a conversion of 75% after 30 minutes. Calcium methoxide was medially active. Magnesium oxide and calcium hydroxide showed no catalytic activity in rapeseed oil methanolysis.
Kouzu et al. (2007), using CaO as a solid base catalyst for trans-esterification of soybean oil with refluxing methanol, found that after 1h of reaction time, the yield of fatty acid methyl ester (FAME) was 93% for CaO, 12% for Ca(OH)$_2$ and 0% for CaCO$_3$. Under the same conditions, sodium hydroxide brought about the almost complete conversion (99%) into FAME.

2.7.3 Effect of catalyst concentration

The amount of catalyst used in the process is another variable to take into account, not only because it determines the reaction rate, but also because it can cause hydrolysis and saponification. Both reactions interfere with the separation of the glycerol rich phase and with the methyl esters purification. Freedman et al. (1984) recommended the use of 1% NaOH or 0.5% NaOCH$_3$ as the optimal concentrations of catalyst. In recent a work (Tomasevic and Siler-Marinkovic, 2003), concentrations of 0.5%, 1.0%, and 1.5% of KOH were studied and the optimum value found was 1% of potassium hydroxide. Leung and Guo tried three different homogeneous catalysts i.e. sodium hydroxide (NaOH), potassium hydroxide (KOH), and sodium methoxide (CH$_3$ONa). The optimum requirements of the catalyst were 1.1, 1.3 and 1.5 wt% for NaOH, CH$_3$ONa, and KOH respectively for the maximum ester content. The reaction was conducted at four different catalyst concentrations, 0.5, 1.0, 1.5 and 2.25 M HCl in presence of 100% excess alcohol and the result was compared with 2.25 M H$_2$SO$_4$. They concluded that, H$_2$SO$_4$ has superior catalytic activity in the range of 1.5–2.25 M concentration to other concentrations.
2.7.4 Effect of temperature

Trans-esterification can occur at different temperatures, depending on the oil used. Several researchers found that the temperature increase influences the reaction in a positive manner (Freedman et al., 1984; Canakci and Van Gerpen, 1999; Srivastava and Prasad, 2000; Encinar et al., 2005). The standard value for the reaction to take place is 60°C, but depending on the type of catalyst, different temperatures will give different degrees of conversion and for that reason, Ma and Hanna proposed that the temperature range should be from 25 to 120°C.

Dorodo et al. (2002) found that the ester yield slightly decreases above 500°C reaction temperature. For the trans-esterification of refined oil with methanol (6:1) and 1% NaOH, Freedman et al. (1984) studied the reaction with three different temperatures. After 0.1 h, ester yields were 94, 87 and 64% for 60, 45 and 32°C, respectively. After 1 h, ester formation was identical for 60 and 45°C runs and only slightly lower for the 32°C run.

2.7.5 Effect of reaction time

A number of researchers have identified reaction time as an important variable that affects the trans-esterification reaction. In 1984, Freedman and his team of researchers using peanut, cotton seed, sunflower and soybean oil under the reaction condition of methanol to oil ratio of 6:1, 0.5% sodium methoxide catalyst and 60°C observed a relationship between the rate of conversion of methyl ester. They observed that the rate of conversion increases with reaction time.

Ma et al. (1998) followed it up, this time using methanol and beef tallow and observed that, the reaction was very slow during the first minute of the reaction but proceeded very
fast after five minutes of reaction. They attributed the slow nature of the reaction at the initial stage to the mixing and dispersion of the methanol into beef tallow. Umer and Anwar (2008) using rapeseed oil, in an alkaline-catalyzed trans-esterification, obtained results, which were in accordance with that of Ma et al. (1998).

2.7 Properties of *Jatropha curcas* seed oil

The chemical compositions of the oil vary according to the climate and locality. The composition of *J. curcas* oil from Nigeria contains mainly fatty acids such as palmitic acid (13%), stearic acid (2.53%), oleic acid (48.8%) and linoleic acid (34.6%) (Martínez-Herrera et al., 2006). Akintayo and Salimon and Abdullah in 2004 and 2008 respectively, studied the physicochemical properties of jatropha seed oils from Nigeria and Malaysia and reported their findings as given in the Table 1. The oil shows a high iodine value due to its high content of unsaturated fatty acids. The seed oils are rich in oleic and linoleic acid hence the oil having a great potential for oleo chemical application such as surface coating and low pour point biodiesel. The oil also contains toxalbumine called curcine and various forms of toxic phorbol esters making it unsuitable for human consumption (Haas et al., 2002). According to Becker and Makkar (1998), several cases of *J. curcas* nut poisoning in humans after accidental consumption of the seeds have been reported with symptoms of giddiness, vomiting and diarrhoea and in the extreme condition even death has been recorded.
Table 1: Physicochemical characteristics of Malaysian *J. curcas* seed oil and Nigerian *J. curcas* seed oil (Akintayo, 2004; Salimon 2008)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Malaysia</th>
<th>Nigeria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iodine value (mg/g)</td>
<td>135.85±1.44</td>
<td>105.20±0.70</td>
</tr>
<tr>
<td>Acid value (mgKOH/g)</td>
<td>1.5±0.07</td>
<td>3.5±0.1</td>
</tr>
<tr>
<td>Saponification value (mg/g)</td>
<td>20.5±0.47</td>
<td>198.85±1.4</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>0.02±0.01</td>
<td>-</td>
</tr>
<tr>
<td>Refractive index at 28º C</td>
<td>1.469</td>
<td>1.468</td>
</tr>
<tr>
<td>Viscosity</td>
<td>36</td>
<td>17-52</td>
</tr>
</tbody>
</table>

Oil quality and consistency is important for producing biodiesel and the physical and chemical content of Jatropha oil can be extremely variable (Patil and Shugu, 2008). Oil characteristics appear to be influenced by environmental and genetic interactions, as are seed size, weight and oil content (Patil and Shugu, 2008). The maturity of the fruits also affect the fatty acid composition of the oil, and processing and storage further affects the oil quality (Achten *et al.*, 2008).

Oil quality is also important when producing Jatropha oil for direct use as a fuel. More investigation is necessary to determine what oil quality can be attained reasonably in
representative rural conditions. In general, it is necessary to ensure low contamination of the oil, low acid value, high oxidation stability and low contents of phosphorous, ash and water. Crude Jatropha oil is relatively viscous, for example, more than rapeseed. It is characteristically low in free fatty acids, which improves its storability, though it’s high unsaturated oleic and linoleic acids make it prone to oxidation in storage. However, the presence of unsaturated fatty acids (high iodine value) allows it to remain fluid at lower temperatures. Jatropha oil also has a high cetane (ignition quality) rating. The low sulphur content indicates less harmful sulphur dioxide (SO₂) exhaust emissions when the oil is used as a fuel. These characteristics make the oil highly suitable for producing biodiesel (Maundu and Tengnas, 2005).

2.8 The ecological zones of Kenya

2.8.1 Zone I

This zone has no direct importance in agricultural production other than being the source of rain and some rivers/streams. It is confined to mountains and immediate surrounding such as Mt. Kenya and Mt Elgon (FAO, 1996).

2.8.2 Zone II

This zone is generally restricted to the highlands of Kenya between 1980 and 2700 m and occurs as a forest or open grasslands. This zone is found in the surrounding of Mt Kenya (parts of Meru, Embu, Kirinyaga and Nyeri), isolated parts of the Rift Valley around Mau and Abadares mountains (e.g around Kericho and Nyahururu respectively) and the surrounding of Mt Elgon (e.g around Kitale and Webuye). The minimum rainfall is 1000mm. The main grasses are *Pennisetum clandestinum* (Kikuyu grass), *Themeda*
triandra (Red oats), Andropogon chrysostachyus, Andropogon pralonsia, Exotheca abisinica, Digiteria scalaram, Eragrostis lascantha, Seteria sphacelata, Pennisetum catabasis and Sporobolus filipes. The legumes include Trifolium johnstoni, Medicago sativa (Alfalfa or Lucerne), Sesbania sesban and Leuceana leucusephala (FAO, 1996).

2.8.3 Zone III

This zone occurs mainly at elevations between 900-1800 m with a annual rainfall between 950 and 1500 mm. Trees are numerous here and somewhat of shorter stature than in Zone II. This zone is the most significant for agricultural cultivation and several legume fodders are found here in crop-livestock systems. It is also the most resettled by human. It occurs in the vast parts of Nyanza, Western and Central provinces, good proportion of Central Rift-Valley (Nandi, Nakuru, Bomet, Eldoret, Kitale) and a small strip at the Coast province. The major grasses are Hyperenia and Cymbopogon, Themeea triandra, Panicum maximum, Seteria Sphacelata, Sporobolus pyramidalis, Bracharia brizantha (Congo signal), Bricharia silita, Chloris gayana (Rhodes grass) and Cynodon dactylon (Star grass) (FAO, 1996).

2.8.4 Zone IV

This zone occupies more or less the same elevation (900-1800 m) as the previous or may be at times lower. However, it has lower rainfall of about 500-1000 mm. This is typically represented in surroundings of Naivasha, vast parts of Laikipia and Machakos districts vast parts of central and southern Coast Province. It is the home of most Acacia trees and shrubs including Acacia seyal, Acasia Senegal, Acacia brevispica, Acacia drepanolobium and Acacia gerrardii. Euphobia trees occur in some drier parts of this zone. Combretum
and Terchonanthus spp. are also common here. Grasses found include Themeda triandra, Pennisetum mezinum, Pennisetum straminium, Pennisetum massaiense, Eragrostis spp., Hyperenia spp. Seteria spp., Digiteria spp., Bothriochloa insculpta, Cenchrus ciliaris. Rare grasses include Chloris spp. and Cynodon spp. Besides acacia, other important legume include Indigofera and Crotolaria (FAO, 1996)

2.8.5 Zone V

This zone is much drier than Zone IV and occurs at lower elevations. Annual rainfall is 300-600 mm. This Zone is prevalent in northern Baringo, Turkana, lower Makueni and vast parts of North Eastern Province. Low trees and shrubs found here include Acacia mellifera, Acacia tortilis, Acacia horrida, Acacia reficiens, Acacia nubica, Acaia paslili, Acacia Zanzibarica, Adansonnia digitata, Terminalia prunioides, Dobea spp., Dioppspyros spp. and Commiphora spp. Common grasses are Eragrostis superba, Cenchrus ciliaris, Cymbopogon spp., Bothriochloa spp. and Heteropogon contortus (FAO, 1996).

2.8.6 Zone VI

This zone is considered as semi desert and is the driest part of Kenya. Annual rainfall is 200-400 mm and is quite unreliable. The zone is found in Marsabit, Turkana, Mandera and Wajir Districts. Dominant in this zone are Acacia and Commiphora shrubs with scattered taller trees of Delonix elata, Acacia tortilis and Adansonnia digitata. Balanites egyptica, Boscia coriacea, Salvadora persica, Acacia mellifera and Acacia reficiens are important shrubs or low tree species. The very common and important dwarf shrubs are Indigofera spinosa and Sansevieria spp. Other important shrubs are Sericomomopsis, Barberia and Duosperma eromophylum. Being the most delicate zone both annual and
perennial grasses are important here. Important grasses include *Aristida adoensis*, *Stipagrostis hirtigluma* are very characteristic and may occur as annuals or perennials. Other grasses also found here are *Aristida mutabilis, Chrysopogon aucheri, Tetrapogon spp, Enneapogon cenchroides, Chloris roxburghiana* (FAO, 1996).

2.8.7 Zone VII

This is represented by Chalbi desert in Marsabit district. The Chalbi is a salt desert with very sparse salt bushes as the only vegetation found. It is vast and of beautiful scenery. Pastoralists use it as a source of mineral lick for livestock, particularly during the rainy season (FAO, 1996).

Meru is in ecological zone II of Kenya. The topography of the district is dominated by the great Nyambene range, which creates the diversity of the physical landscape that affects the physiographic and the entire environment of the district. The district lies between an altitude of 2,514 M at the summit of the Nyambene range and 300M above sea level in the Meru National Park bordering Tana River District (FAO, 1996).

Kibwezi is in the southern portion of Makueni District. The altitude of the area varies from 600M to 1100M. The area lies in the agro-climatic and ecological zone V of Kenya. It is characterised by low and unreliable rainfall, marginal agricultural lands, dispersed population and low fertility soils (FAO, 1996).

Funyula is in Busia District and falls within the Lake Victoria Basin. The altitude varies from 1,130m above sea level on the shores of Lake Victoria to 1,375m above sea level in the central part (GoK, 2002). The area lies in ecological zone 111 (FAO, 1996).
Oyugis lies in ecological zone III. This zone occurs mainly at elevations between 900-1800 m. This zone is the most significant for agricultural cultivation (FAO, 1996).
CHAPTER THREE

MATERIALS AND METHODS

3.1 Sample collection sites
Jatropha seeds were obtained from Kibwezi, Meru/Tharaka, Oyugis and Funyula locations. It involved random sampling of various cultivated seed bearing jatropha trees where three samples 10 Kg each of dry mature jatropha seeds were collected from each site.

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

$$MC\,(\%) = \frac{(M_i - M_f) / M_i} \times 100\%$$
Where MC (%) is the moisture content, \( M_i \) is the initial mass and \( M_f \) is the final mass of the seed (Dingman, 2002).

### 3.3 Extraction of oil samples

The test samples of the vegetable oil were extracted from the whole seeds using ram press method. The ram press operates by applying pressure to seeds inside a cylinder and cage by means of a piston and a system of levers. Under the pressure built in the cage the seeds release oil, which flows out through the slots available in the cage. The remaining cake is forced out at the other end of the cage past a conical restrictor. When the handle is raised, seeds drop down from a hopper through the inlet port into the cylinder. Then the piston is moved forward when the handle is lowered, pushing the seeds into the cage under increasing pressure. When the pressure has risen enough, oil is squeezed out of the seeds and drips from the cage through the cage slots. Cake is extruded from the opposite end of the cage provided that sufficient pressure has been built up in the cage. The latter is controlled by means of the adjustable restrictor (Uziak and Loukanov, 2007). The crude oil extracted was filtered through an ashless filter paper (Whatman Filter paper).

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

\[
\% \text{ of oil} = \left( \frac{\text{Weight of oil obtained in grams}}{\text{Weight of seed taken in grams}} \right) \times 100
\]
3.4 Chemical and physical analysis of jatropha seed oil

3.4.1 Moisture

The extracted crude jatropha oil was analysed for its moisture levels using the procedure outlined in section 3.2 and the moisture content (MC) of the Jatropha oil was then calculated using the equation below:

\[ MC(\%) = \frac{(M_i - M_f)}{M_i} \times 100\% \]

Where MC (\%) is the moisture content, \( M_i \) is the initial mass and \( M_f \) is the final mass of the seed (Dingman, 2002).

3.4.2 Density

The density of the oils and water were determined using a density bottle with a provision for temperature measurement. An empty density bottle of known volume was weighed before being filled with the sample and reweighed at 20°C. All weights were determined to the nearest 0.0001 g and in duplicate while ensuring that the difference between the two weights did not exceed 0.0002 g. The density of the samples was then calculated using the relationship below (Kopeck’y, 1999).

\[ \text{Density} = \frac{\text{Mass of oil}}{\text{Volume of oil}} \]

3.4.3 Acid value and free fatty acids

A 25 ml of diethyl ether was mixed with 25 ml alcohol and 1 ml phenolphthalein solution (1 % W/V) and carefully neutralized with 0.1 M sodium hydroxide. Five grams of Jatropha oil was dissolved in the mixed neutral solvent and titrated with aqueous 0.1 M
sodium hydroxide shaking constantly until a pink colour which persisted for 15 seconds was obtained. The following equation was used to calculate the acid value (Robinson and Stockes, 1959).

\[ \text{Acid value} = \text{titration (ml)} \times \frac{5.61}{\text{weight of sample used}} \]

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

3.4.4 Saponification value

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

Two grams of oil was weighed into a conical flask and exactly 25 ml of the alcoholic potassium hydroxide solution added. A reflux condenser was attached and the flask was heated in water for 1 hour, shaking frequently. One ml phenolphthalein solution (1%) was added and the excess alkali titrated hot with 0.5 M hydrochloric acid (titration = \(a\) ml). A blank was carried out at the same time (titration = \(b\) ml). The following equation was used to calculate the saponification value (ASTM D5558):

\[ \text{Saponification value} = \frac{(b-a) \times 28.05}{\text{wt (in g) of sample}} \]

3.4.5 Refractive index

Refractive index of Jatropha seed oil was determined using Abbey refractometer, Atago 3T type. A drop of the sample was transferred into a glass slide of the refractometer. Water at 30°C was circulated round the glass slide to keep its temperature uniform.
Through the eye piece of the refractometer, the dark portion viewed was adjusted to be in line with the intersection of the cross. At no parallax error, the pointer on the scale pointed to the refractive index. This was repeated and the mean value noted and recorded as the refractive index. The tests were done to the nearest 0.001 allowing a difference of less than 0.002 between the replicates.

3.4.6 Iodine value

A 20 ml of carbon tetrachloride (CCl₄) was added to 0.24 g of the Jatropha seed oil in 250 ml Erlenmeyer flask. Another 20 ml of the carbon tetrachloride were added to two additional flasks that served as blanks. A 25 ml volume of Wij’s reagent was pipetted into each flask. The flasks were corked, swirled to mix content and stored in a dark place at 28 °C. Ten ml of 30% W/V potassium iodide (KI) and 100 ml of purified water were added to the sample solution after 30 minutes of storage and immediately titrated with standard 0.1 M sodium thiosulphate (Na₂S₂O₃) until the yellow colour almost disappeared. One ml of 1%W/V starch indicator solution was added and the titration continued, this time drop wise with vigorous swirling until the disappearance of the blue starch-iodine colour. The blanks were titrated in the same manner (AOAC Official Method-1997 993.20.). The iodine value was calculated using the below equation:

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

3.4.7 Calorific value

Adiabatic bomb calorimeter (Parr instrument company, 1982) was used in the experiment. The effective heat capacity of the calorimeter was determined using benzoic acid of a certified calorific value of 26.4698 MJ/kg under standard conditions. About 1 ml
of distilled water was pipetted into the bomb. An accurately weighed sample of the order of 0.5 g was introduced into the oil cup and placed in the bomb. A length of fine cotton thread was suspended in the sample from a nickel-chromium wire in order to act as a source of ignition. The bomb was assembled and charged with oxygen at 35 atmospheres. The initial temperature of the calorimeter was adjusted to about 275 °K below ambient temperature to minimize heat losses. After about five minutes of natural heat transfer to the jacket water, the firing circuit was closed, and the temperature of the jacket water recorded until it was found to fall for a period of about five minutes. The temperature rise was noted and the net calorific value was calculated using the equation below (Shoemaker et al., 1996). The experiment was carried out in triplicate allowing a difference of about 0.28 MJ/Kg between the values obtained.

**Calculation:**

Calorific value (cal/g) = (water equivalent (g) + water quantity of inner cylinder) × raised temperature (°C) – calory correction /quantity of sample (g) (Shoemaker et al., 1996).

**3.5 Trans-esterification process**

Base catalyzed trans-esterification process was selected as it is a simpler process and requiring low temperatures. Base catalyzed trans-esterification was carried out in a 250mL conical flask equipped with a magnetic stirrer. Oil (50g) was taken in flask and sodium hydroxide (1 Percent of fat’s weight) dissolved in methanol (22.5 percent of oil’s weight) was added to flask. Stirring was continued for two hours at room temperature, the mixture was transferred to a separating funnel and glycerol was allowed to separate and washed (Rice et al., 1997).
3.6 Physicochemical analysis of biodiesel produced from *Jatropha curcas* seed oil

3.6.1 Moisture content

The extracted crude jatropha oil was processed into jatropha biodiesel using transesterification process. The biodiesel was also analysed for its moisture levels using the procedure outlined in section 3.2. The moisture content (MC) of the Jatropha biodiesel was then calculated using the equation below (Dingman, 2002).

\[
MC(\%) = \left\{ \frac{(M_i - M_f)}{M_i} \right\} \times 100\%
\]

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

3.6.2 Density and relative density

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

3.6.3 Kinematic Viscosity

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

\[ V = C \times t \]

Where

\[ V = \text{kinematic viscosity, mm}^2/\text{s} \]

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

\[ t = \text{mean flow time, s} \]
3.6.4 Flash-point

Standard test methods for flash-point by Pensky-Martens closed cup tester was used (ASTM D93-13). A brass test cup of specified dimensions, filled to the inside mark with test specimen and fitted with a cover of specified dimensions was heated and the specimen stirred at specified rates. An ignition source was directed into the test cup at regular intervals with simultaneous interruption of the stirring, until a flash was detected. The flash point in petroleum products is the lowest temperature corrected to a barometric pressure of 101.3 kPa (760 mm Hg) at which an application of an ignition source causes the vapours of a specimen of the sample to ignite under specified conditions of test.

Flash and fire points were determined using the closed cup Pensky-Martens flash tester (ASTM D93-13). The oil sample was filled into the tester cup up to the mark and covered. The sample was stirred for about five minutes and its temperature noted. A standard test flame was added to the vapour space at an interval of about 278 °K rise while continuously heating the sample at a constant rate until flame that flashes the air-vapour mixture appeared. The sample temperature ($E_F$) was noted as the flash point. The sample was further heated while repeating the above procedure until the air-vapour mixture started to burn continuously for about 5 seconds. The sample temperature ($E_{Fr}$) was noted as the fire point. The values obtained were duplicated and reported to within ±8 °K accuracy.
3.6.5 Acid value and free fatty acids

Jatropha biodiesel was analysed for its acid values using the procedure outlined in section 3.4.3. The acid value was calculated by the below equation (Robinson and Stockes, 1959).

\[ \text{Acid value} = \frac{\text{titration (ml) } \times 5.61}{\text{weight of sample used}} \]

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

3.6.6 Calorific value

Calorific value for biodiesel was also determined using the procedure outlined in section 3.4.7. The calorific value was calculated by the below equation (Shoemaker et al., 1996):

\[ \text{Calorific value (cal/g)} = \frac{\text{(water equivalent (g) + water quantity of inner cylinder) \times raised temperature (°C) – calory correction}}{\text{quantity of sample (g)}} \]

3.6.7 Refractive index

Refractive index of Jatropha biodiesel was determined using Abbey refractometer, Atago 3T type. A drop of the sample was transferred into a glass slide of the refractometer. Water at 30°C was circulated round the glass slide to keep its temperature uniform. Through the eye piece of the refractometer, the dark portion viewed was adjusted to be in line with the intersection of the cross. At no parallax error, the pointer on the scale pointed to the refractive index. This was repeated and the mean value noted and recorded as the refractive index. The tests were done to the nearest 0.001 allowing a difference of less than 0.002 between the replicates.
CHAPTER FOUR

RESULTS

4.1 Quantity and quality characteristics of oil yield

In this study, the accession with the highest oil yield per weight was from Meru with 38.8% oil content, while those from Funyula and Oyugis were 28.4% and 27.0%, respectively. The least was from Kibwezi with 23.1% (Table 2). According to Achten et al. (2007) the expected oil yield ranges for *J. curcas* seeds that can be processed to produce a high quality biodiesel fuel is 27 to 40% (average 34.4%).

**Table 2**: Quantity of oil produced from the various regions in Kenya.

<table>
<thead>
<tr>
<th>Region</th>
<th>Percent yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kibwezi</td>
<td>23.1 ± 0.3</td>
</tr>
<tr>
<td>Oyugis</td>
<td>27.0 ± 0.2</td>
</tr>
<tr>
<td>Meru</td>
<td>38.8 ± 0.2</td>
</tr>
<tr>
<td>Funyula</td>
<td>28.4 ± 0.1</td>
</tr>
</tbody>
</table>

Values are mean ± SD of triplicate determinations triplicate

4.2 Physicochemical properties of *Jatropha curcas* seed oil

In this study, *J. curcas* accessed from Kibwezi showed the lowest moisture content (0.08275 ml) with those accessed from Funyula revealing higher levels (0.18525 ml) (Figure 1). Moisture is a chemical contaminant which is mixed with lubricating oil like...
Jatropha oil, and it is the major cause of most engine failure; hence the moisture content reported herein was lower than 0.2% as reported for Jatropha oil (Tint and Mya, 2009).

![Moisture content of the oil produced by *J. curcas* from various regions in Kenya.](image)

**Figure 1:** Moisture content of the oil produced by *J. curcas* from various regions in Kenya.

The saponification value of crude *J. curcas* seed oil from Meru and Oyugis was the same (120.6), but slightly higher compared to the *J. curcas* seed oil from Funyula and Kibwezi which had almost similar saponification values of 112.2 and 113.6, respectively (Figure 2).
Figure 2: Saponification values of the oil produced by *J. curcas* from various regions in Kenya.

Jatropha seed oil accessed from Oyugis had the highest acid value (4.19 mgKOH/g) with the least values being from Funyula (1.35 mgKOH/g) (Figure 3). Compared to the maximum amount recommended for oils to be used for biodiesel production, these values are still higher. Ideally the oil’s acid value should be less than 1 mgKOH/g with all raw materials being anhydrous (water content < 0.3%) (Freedman *et al.*, 1984).
The iodine value of Jatropha oil was determined to be 99.17 g I$_2$/100g for Kibwezi, 91.56 g I$_2$/100g for Meru, 80.77 g I$_2$/100g for Oyugis and 71.25 g I$_2$/100g for Funyula (Figure 4). Standard iodine value for biodiesel is 120 for Europe’s EN 14214(2003) specification.

**Figure 3**: Acid value of the oil produced by *J. curcas* accessed from various regions in Kenya

**Figure 4**: Iodine value of oil produced by *J. curcas* from various regions in Kenya
The density of crude Jatropha seed oil was 1.0808 g/cm³ (Meru), 1.0814 g/cm³ (Funyula), 1.0864 g/cm³ (Kibwezi) and 1.0802 g/cm³ (Oyugis) at 20°C (Figure 5). The standard for diesel engine fuel states that the fuel should have a density between 0.86 and 0.90 g/cm³, thus crude jatropha oil is unsuitable for direct usage as a substitute for diesel fuel.

![Density (g/cm³)](image)

**Figure 5**: Density of oil produced by *J. curcas* accessed from various regions in Kenya.

**Table 3**: Summary characteristics of the various parameters of oil in the regions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>4</td>
<td>0.129</td>
<td>0.052</td>
<td>0.083</td>
<td>0.185</td>
</tr>
<tr>
<td>Saponification</td>
<td>4</td>
<td>116.760</td>
<td>4.494</td>
<td>112.200</td>
<td>120.620</td>
</tr>
<tr>
<td>Acid value</td>
<td>4</td>
<td>2.913</td>
<td>1.267</td>
<td>1.346</td>
<td>4.189</td>
</tr>
<tr>
<td>Iodine value</td>
<td>4</td>
<td>85.680</td>
<td>12.236</td>
<td>71.250</td>
<td>99.170</td>
</tr>
<tr>
<td>Density value</td>
<td>4</td>
<td>1.082</td>
<td>0.003</td>
<td>1.080</td>
<td>1.086</td>
</tr>
</tbody>
</table>
4.3 Physicochemical properties of *Jatropha curcas* biodiesel

The mean density of biodiesel produced from the regions in Kenya was not different from the required standard value of 0.86 to 0.9 g/cm³ (Table 4), thus the biodiesel is suitable for direct usage as a substitute for diesel fuel.

The kinematic viscosity of the biodiesel samples produced in this work range from 4.3 to 4.8 mm²/s at 40°C (Table 4). For biodiesel to be used in diesel engines, the kinematic viscosity must be between 1.9 and 6.0 mm²/s at 40°C according to ASTM recommended level. These results are within the standard requirements.

The water content in all samples of the biodiesel was reduced to the acceptable levels of less than 0.05% (Table 4) the mean moisture content of biodiesel produced is not different from the standard ASTM requirement of 0.05. EN 14214 (2003) imposes a maximum content of 0.05% of water in fuels.

Considering that the presence of free fatty acids influences fuel aging, the European Standard specifies a maximum acid value of 0.5 mg of KOH/g of sample. The acid value in the biodiesel produced is not different from the hypothesized value of 0.5 (Table 4).

The flashpoint of biodiesel is generally over 150°C, much greater than the ASTM specifications of 130 minimum required. From the results there is evidence that the mean flashpoint of biodiesel produced is greater than the required 130°C (Table 4); therefore, jatropha biodiesel is safe to handle.
Table 4: Mean values of biodiesel accessions from various sites in Kenya

<table>
<thead>
<tr>
<th>Region</th>
<th>Density at 20°C (g/cm³)</th>
<th>Flashpoint (ºC)</th>
<th>Kinematic viscosity (mm²/s)</th>
<th>Moisture content (%)</th>
<th>Acid value (mgHOK/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meru</td>
<td>0.8786</td>
<td>164.5</td>
<td>4.321</td>
<td>0.3725</td>
<td>0.34</td>
</tr>
<tr>
<td>Funyula</td>
<td>0.8791</td>
<td>186.5</td>
<td>4.4256</td>
<td>0.04</td>
<td>0.31</td>
</tr>
<tr>
<td>Kibwezi</td>
<td>0.8808</td>
<td>182.5</td>
<td>4.7862</td>
<td>0.05</td>
<td>0.86</td>
</tr>
<tr>
<td>Oyugis</td>
<td>0.8801</td>
<td>156.5</td>
<td>4.6375</td>
<td>0.04</td>
<td>0.67</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.000</td>
<td>7.165</td>
<td>0.105</td>
<td>0.08</td>
<td>0.135</td>
</tr>
<tr>
<td>ASTM</td>
<td>0.86-0.9</td>
<td>130</td>
<td>1.9-6.0</td>
<td>0.05</td>
<td>0.5</td>
</tr>
<tr>
<td>Standard</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5: Biodiesel characterization

<table>
<thead>
<tr>
<th>Test name</th>
<th>Density at 20°C (g/cm³)</th>
<th>Flashpoint (°C)</th>
<th>Kinematic viscosity (mm²/s)</th>
<th>Acid value (mgHOK/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel WCO</td>
<td>0.8889</td>
<td>172</td>
<td>8.2</td>
<td>0.22</td>
</tr>
<tr>
<td>Biodiesel WVF</td>
<td>0.8958</td>
<td>168</td>
<td>12.3</td>
<td>0.83</td>
</tr>
<tr>
<td>Biodiesel from sunflower oil</td>
<td>0.8855</td>
<td>180</td>
<td>6.8</td>
<td>0.11</td>
</tr>
<tr>
<td>ASTM Standard</td>
<td>0.86-0.9</td>
<td>130</td>
<td>1.9-6.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

(Source: Mbatia, 2013)

Table 6: Summary of biodiesel parameters measured from the regions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density20°C</td>
<td>4</td>
<td>0.88</td>
<td>0.00</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>Flashpoint</td>
<td>4</td>
<td>172.50</td>
<td>14.33</td>
<td>156.50</td>
<td>186.50</td>
</tr>
<tr>
<td>Kinematic viscosity</td>
<td>4</td>
<td>4.54</td>
<td>0.21</td>
<td>4.32</td>
<td>4.79</td>
</tr>
<tr>
<td>Moisture</td>
<td>4</td>
<td>0.13</td>
<td>0.16</td>
<td>0.04</td>
<td>0.37</td>
</tr>
<tr>
<td>Acid value</td>
<td>4</td>
<td>0.55</td>
<td>0.27</td>
<td>0.31</td>
<td>0.86</td>
</tr>
</tbody>
</table>
CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 DISCUSSION

From the results, jatropha seeds from Meru would be the most preferred as a biodiesel feedstock as it would consequently result in higher yield in biodiesel. These variations may be as a result of their different geographical locations.

The low moisture content shows that the oil is of good quality and could not be easily subjected to contamination/rancidity (Fellows, 1997). It is noteworthy that free fatty acids and moisture have significant effect on the trans-esterification of glyceride with alcohol using catalysts (Goodrum, 2002). As a result of the hygroscopic nature due to high polarity of fatty acid methyl esters, biodiesel tends to absorb water during the final washing step in the production process and during storage. Free water promotes biological growth which may cause blockage of fuel filters and fuel lines as a result of induction of sludge and slime formation. Moreover, high water content is also associated with hydrolytic reaction which partly converts fatty acid methyl esters into free fatty acids which are linked with filter blockages as well (Mittelbach et al., 1999). Fuel contaminated with water can cause engine corrosion or react with the glycerides to produce soaps and glycerine.

The similarity in saponification value between the Meru J. curcas seed oil and that of Oyugis, and the near similarity between Funyula and Kibwezi may be due to similarity in the fatty acid composition as a result of similar soil and climatic conditions in each of the areas. The saponification value is an important parameter in jatropha oil production as
higher saponification values indicate the normality of the oil as triglyceride which is very useful in the production of liquid soap and shampoo.

The acid value gives an indication of the quality of fatty acids in the oil. This value is dependent on a number of factors which include the type of feedstock used for the fuel production, production process and its respective degree of purification. The transesterification process is still possible even if these requirements are not met, but the yield of the reaction will be reduced due to the deactivation of the catalyst and the formation of soaps. High acid values also affect the purity of the biodiesel. It further makes separation relatively more difficult compared to oil with lower acid value (Freedman et al., 1984). The acid value measures the content of free fatty acids and mineral acid in biodiesel. Corrosion of chromium and zinc parts within the engine and injection system has been linked to high acidity of the fuel (Cvengros, 1998).

Iodine value is an important measure that allows determination of the degree of unsaturation in fuels (Knothe, 2002). This property greatly influences fuel oxidation and the type of aging products and deposits formed in diesel engine injectors. The limitation of unsaturated fatty acids is necessary due to the fact that heating higher unsaturated fatty acids results in polymerization of glycerides. This can lead to the formation of deposits or to deterioration of the lubricating oil (Mittelbach, 1996). The iodine values of J. curcas place them in the semi-drying oil group. High iodine values of Jatropha are caused by high content of unsaturated fatty acid such as oleic acid and linoleic acid with most Jatropha seed oil consisting of 78.5% unsaturated fatty acid (Akintayo, 2004).
Density is an important property mainly in airless combustion systems because it influences the efficiency of atomization of the fuel. The density of a vegetable oil is lower than that of water and the differences between vegetables oil are quite small, particularly amongst the common vegetable oils. Generally, the density of oils decreases with molecular weight yet increases with unsaturation level. Lower value of the density of biodiesel is an indication of completion of reaction and removal of heavy glycerine (Foidl et al., 1996).

Kinematic viscosity of the biodiesel is within the standard requirements. This is an important factor as it would ensure complete burning of the fuel without any ignition delay. Higher viscosity leads to a higher drag in the injection pump and thus causes higher pressures and injection volumes more especially at low engine operating temperatures. Viscosity is also an indication of fuel aging during storage as it increases due to polymerization induced by oxidative degradation (Canakci et al., 1999).

Flash point is the lowest temperature at which application of the test flame causes the vapor and air mixture above the sample to ignite. Flash point helps to monitor the safe handling and storage of fuel. The higher the flash point the safer the fuel and vice versa. The flash point of biodiesel is higher than that of fossil diesel (52 °C); therefore it could be said that biodiesel is safer to handle than fossil diesel. Biodiesel falls under the non-hazardous category of the National Fire Protection association codes (Patil and Singh, 1991).
5.2 CONCLUSIONS

From the results obtained, jatropha seeds from Meru produced the highest quantity of oil, therefore making it the most preferred as a biodiesel feedstock as it would consequently result in higher yield in biodiesel. The quality characteristics of the oil produced clearly demonstrate that crude jatropha oil is unsuitable for direct usage as a substitute for fossil diesel fuel; it has to undergo trans-esterification due to its high density and acid values so as to reduce them to acceptable levels. The physicochemical properties of biodiesel produced meet the ASTM specifications. The density, kinematic viscosity, flashpoint, calorific value, refractive index and acid value of biodiesel produced in the present study are within the standard ascribed by ASTM and are also similar to those of fossil diesel. However, the acid levels of biodiesel produced from Kibwezi and Oyugis were found to be somewhat higher, which may point to corrosion of chromium and zinc parts within the engine and injection system (Cvengros, 1998). Therefore, fatty acid levels must be reduced to the optimum levels for it to be used as a substitute for diesel fuel. As compared to the quality of biodiesel from waste vegetable fat (WVF), waste cooking oil (WCO) and sunflower oil (Mbatia, 2013), jatropha would be the most suitable feedstock for biofuel production.

It can be concluded from this study that the biodiesel produced from J. curcas oil is a potential replacement for fossil diesel. The production and effective usage of biodiesel will help to reduce the cost of protecting the atmosphere from the hazards in using fossil diesel and hence will boost the economy of the country.
5.3 RECOMMENDATIONS

• Further studies should be carried out on other accessions of jatropha in Kenya such as in Kajiado, Namanga, Nakuru, Naivasha, Kitui, Malindi and Thika to determine the most suitable provenance to be developed and improved and to investigate their true production potential and the corresponding agronomic treatments required to achieve reproducible high yields of *J. curcas* in varied ecological environments as this study was based on only four sites.

• There is need to explore other methods of biodiesel production such as supercritical process, ultrasonic reactor method, ultra-and high-shear in-line and batch reactors and lipase catalysed methods so as to determine the most effective method of trans-esterification that would result in higher quantity and quality of biodiesel.

• Other sources of biofuel should be explored such as croton, rapeseed, soybean, mustard, canola, palm oil and waste vegetable oil and compared with the use of jatropha, to determine a biofuel feedstock with the highest potential and benefits to be developed in Kenya for biodiesel production.
REFERENCES


