Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 5 (2023)

Comparative Case-study and Testing of *Moringa oleifera* Seed-oil as Biodiesel Fuel Feedstock

[1]Andrew C. Eloka-Eboka, [2]Freddie L. Inambao

[1][2] Department of Mechanical Engineering,
University of KwaZulu-Natal, Howard College, Durban 4000, South Africa.

Abstract:
Development of first, second and third generation of biodiesel fuels in Africa has been under serious research though with emphasis more on biofuels while biomass and algae are still emerging. The present study explores the prospects and potentials of Moringa oleifera seed-oils as a viable and sustaining second generation biodiesel alternative for use in internal combustion engines and other applications. Chemophysical properties, FT-IR and GC-MS determination, oil yields, thermal and gaseous emission characteristics, rheological and combustion parameters were explored and evaluated in comparison with other known feedstocks in conformity with the American Society for Testing and Materials (ASTM). Higher oil recovery and quality (having oleic acid, a major fatty acid component of biodiesel > 70%), production of the highest grades of biodiesel and glycerine by-product, no direct competition with food crops, more sustainable biodiesel feedstock than Jatropha oil (currently the world's best option), better oxidative stability than most feedstocks, fast plant growth and growability in all Southern African regions, semi-arid, subtropical, semi-nutritious, saline and waste lands of the world characterize Moringa plant feedstock also known as the miracle plant/tree. As a new player in the alternative fuel market, its global potential is massive even as it is projected to be Japan and Korea's dominant source of biodiesel for automobiles within the next fifty years. Southern Africa may trail behind with establishment of plantations and processing facilities.

Keywords Comparative, case study, *Moringa oleifera*, biodiesel, Africa, fuel, feedstock, development, renewables.

1. Introduction

Moringa is a local plant that can enhance Africa's chances of meeting the Millennium Development Goals (MDG's). The socio-economic benefits of developing the entire value chain of this plant cannot be quantified. It grows in all parts of the continent of Africa and incidentally, it grows in the wild [1] [2]. Based on our findings, few plantations have been established in Southern Africa; in Cape Town, Port Shepstone, Pretoria, experimental farms were established for the development of biodiesel industry. Mozambique is developing a Moringa biofuels industry with the hope of contributing to 15 percent of the national fuel consumption in the next five years. Situated in the Ocean coast of Southern Africa, the Republic of Mozambique is an emerging market and is growing rapidly compared to its developed counterpart. Mozambique is currently positioning itself as a major biofuel's producer. Biofuels projects in the country started in 2007 and so far, foreign companies have invested approximately US$ 710 million. Commercial sustainability of Moringa oleifera has proven itself over the past decade with the investment project the first of its kind for the wonder plant which confidently returns 14.5% for the harvest and sale of the crop with constant harvest and sales of the seeds. Global energy companies are purchasing post-harvest for biodiesel production [3]. Platinum Management Associates have established first biofuel station in Africa. Though the global market price for Moringa oil is its infancy, researchers foresee prices equal to that of crude soybean oil (currently US$ 871 * per MT) for biodiesel or crude palm oil (currently US$798* per MT) [3].

Moringa is supported for water treatment in replacement of alum, Senegal is exploiting Moringa to deal with malnutrition in children, Ghana is making tremendous efforts in using the leaves for nutritional supplements, and others are exploiting the seeds for its oil and the roots and barks for medicinal purposes. In

Nigeria, the Raw Materials Research and Development Council (RMRDC) is already domesticating across the country; one will find its products being marketed everywhere in Nigeria. In Southern Africa, Zimbabwe and Mozambique, plantations have been established and fueling stations based on Moringa biodiesel have been established. In South Africa, biodiesel researchers are making effort to position biomass bioenergy with Moringa and Jatropha at the forefront. Some plantations are at the pioneering stages. Moringa had some potential for the benefit of mankind. There is ongoing research by the Green Energy Solution Research Group at the University of KwaZulu-Natal, South Africa to explore and exploit Moringa for the internal combustion engines. The Department of Agriculture in Malawi has set up a system to develop the plant's seed for use as feedstock in the biofuel production. The Moringa Oil Manufacturing Plant of SECRA in Malawi is intending to use the oil harvested from the Moringa seeds to produce biodiesel which will be exported to the United States [3]. The plant's capacity is to produce 150 million gallons of Moringa seed oils per year. The initial capacity of the feedstock plantation is 30,000 hectares already established and then eventual scale up to 100, 000 hectares. Moringa oleifera is a popular plant where, for ages, the leaves, roots and bark have been exploited for food and medicines [4] [5][6][7]. It is probably this long-standing use of the plant by the locals and the positive results alluded to, that have engendered the current wave of research by many of the stakeholders. While Moringa oil is already being anticipated as a source of second-generation biodiesel, it wasn't considered to be an oil source by many because it has so many food sources [8-9]. However, experts have advocated its use as a viable and sustainable biodiesel feedstock hence this study is timely. Moringa can yield about 3 tons of seed per hectare [6] [8]. The seeds contain 30 to 40 percent oil that is high in oleic acid and the meal yields about 61 percent protein as this study will also reveal. It has better oxidative stability than any known biodiesel feedstock and the seeds are relatively easy to crush using non-solvent-based crushing techniques [1-5] [7] [10-11]. The tiny Moringa leaves are believed to prevent over 300 diseases. Now, modern science is proving that these tiny leaves are packed with incredible nutrients (protein, vitamins and iron) that can strengthen our bodies, provide immunity against HIV/AIDS and prevent diseases [11]. Current global developments on Moringa are in consonance with addressing current global issues of hunger, malnutrition, poverty alleviation, water and sanitation, wealth creation and environmental concerns. Today the plant is being used to alleviate poverty among rural dwellers by promoting income generation through rational utilization of vegetation, application of the seed in water treatment, plantation/nursery development, as well as food supplement to combat malnutrition, supply of the leaf powder, oil, etc. Over the past decade, findings on the multi-faceted economic uses of the plant have featured in many scientific journals [1-10] [11]. The plant has become even more relevant considering what it can contribute to achieving some aspects of the MDGs. For this reason, many people refer to it as a "Millennium plant" or "MDGs plant resource". The paradox of this plant is that it has its natural habitat, grows and thrives in those parts of the world identified as poor, underdeveloped, and developing Countries of Asia, Africa, South/Latin America and the Caribbeans. However, in Nigeria where the plant thrives very well and growing mainly in the wild through some natural dispersion method, its potentials are yet to be fully harnessed [1-4]. This paper will review research findings on the plant and its cultivation which is currently being actively promoted in many developing countries. It will also consider various uses and products of the tree with presentations to cover areas of food security, nutritional supplements, medicine, water treatment and other chemicals, renewable energy, ornamentals and environmental concerns. Moringa oleifera (syn. M. pterygosperma) which belongs to the family Moringaceae, is widespread throughout the tropics. It is a small, graceful tree with sparse foliage, white flowers and long pods, native to Arabia and India but widely distributed in Old World tropics, common in northern regions and cultivated in India in ancient times [6]. In Africa, Moringa trees are distributed both in the south and north where it features as a multipurpose tree providing items of food, medicine, household, water treatment, farming system among other uses such as revenue generation through products formulation [8, 9]. Figure 1 shows the world map where Moringa can thrive [3]. The tree is regarded as a miracle and life-saving resource with enormous nutritional and medicinal benefits readily providing the needs of local populace. Its choice as a national crop, worthy of intensive and widespread development, in order to enhance the realization of socio-economic growth and development in Africa and as a whole is therefore most timely.

Figure 1: Map indicating Moringa thriving Areas of the *world.*

1.2 Evaluation of Moringa

The prospects and potentials of Moringa oleifera plant and seed oil are too enormous to be contained in any research study. This paper is addressing its huge potentials as a biodiesel/biofuel feedstock and so will not dwell much outside this scope despite its indispensable utilization in various medicinal, food, water treatment and nutritious industries. Opportunities for commercial development and enhanced utilization of *Moringa oleifera* and several products of nutritional, medicinal, fuel and other uses are feasible from *Moringa* leaves and pods, among other parts. These include the following: (i) Fats and oil; (ii) Leaf powder, as immune booster; (iii) Livestock feeds; (iv) Water purifier, like alum; (v) Fertilizer for soil improvement and increased crop production; (vi) Medicinal products including headache reliever, arthritis; rheumatic pains treatment; (vii) Wood products; (viii) Pulp and paper. These products require intensification and further studies as well as promotion and financial investment or support. The product formulation also calls for intensive raw material production, as suggested later and that is why at the University of KwaZulu-Natal (UKZN)'s Green Energy Solution Research Group of the Discipline of Mechanical Engineering, there is ongoing extensive research work on Moringa biodiesel utilization in diesel engines of the different blends and hybrids to be formulated and their responses thermally during combustion in the engine. Part of these studies is this preliminary being presented in this paper. The engine testing facilities is being modified to suit the current research.

Figure 2: Engine Test cell facilities and IC Engines *at UKZN for Moringa biodiesel experimentation*

1.3 Moringa's potential advantages as a biodiesel feedstock

Moringa oleifera Lam (synonym: *Moringa pterygosperma* Gaertner) belongs to a monogenetic family of shrubs and tree, Moringaceae and is considered to have its origin in Agra and Oudh, in the northwest region of India, south of the Himalayan Mountains. It is a fast-growing tree and has been found to grow to 6 – 7 m in one year in areas receiving less than 400 mm mean annual rainfall [12] [13]. In Durban, South Africa where it was experimented for growability, Moringa attained a growth height of 4 – 5 m within three months of planting and in the fourth month started flowering. Figure 4 shows the sprouted flowers at the fourth month of planting. The plant possesses many valuable properties which makes it of great scientific interest. These include the high protein content of the leaf's twigs and stems, the high protein and oil contents of the seeds, the large number of unique polypeptides in seeds that can bind to many moieties, the presence of growth factors in the leaves. Fresh leaves contain about 30% crude protein on dry matter basis [13] [14]. *M. oleifera* leaves have essential amino acids, including the sulphur-containing amino acids in higher levels (Makkar and Becker, 1997), and with patterns like those of soybean seeds [14]. *Moringa* leaves act as a good source of natural antioxidant due to the presence of various types of antioxidant compounds such as ascorbic acid, flavonoids, phenolics and carotenoids [11] [12]. Its anti-oxidative power surpassed all other known vegetable oil as expressed in Figure 4. *Moringa* leaves are always available throughout the whole year. In West Africa, Moringa leaves appear at the end of the dry season, when there are few other sources of leafy green vegetables [15]. The fast growing, drought-tolerant Moringa tree can tolerate poor soil, a wide rainfall range (25–300+ cm per year), and soil pH from 5.0 to 9.0 [8]. When fully mature, dried Moringa seeds are round or triangular and the kernel is surrounded by a lightly wooded shell with three papery wings; the seeds can produce between 33% and 41% w/w of vegetable oil [9]. Several researchers have investigated the composition of Moringa oil, including its fatty acid profile [9–12, 16-19] and have shown that Moringa oleifera oil is high in oleic acid (>70%). The Moringa tree, *Moringa oleifera,* has probably been the most popular plant in ECHO's seed bank of underutilized tropical crops. The tree is native to India but has been planted around the world and is naturalized in many locales. This oil possesses significant resistance to oxidative degradation and has been extensively used in the effleurage process [15]. Moringa oleifera oil has many medicinal uses and has significant nutritional value [11]. The most conspicuous property of biodiesel derived from the said oil is the high cetane number of approximately 67, which is among the highest reported for a biodiesel fuel [14]. Non-edible feedstocks are easily available in developing countries and are very economical in comparison to edible oils [15].

1.4 Moringa as source of domestic and industrial oil

The seeds of *Moringa* yield 38-40% edible oil known as Ben oil. This oil is relatively easy to extract using simple household technology and can be employed in variety of uses as vegetable oil for cooking (it is colourless, odourless and resists rancidity), cosmetics (it has properties which are very nourishing for the skin), perfumes, lubricant for machinery, and soap making (Ferrao and Ferrao, 1970; Ramachandran *et al.*, 1980). Exploiting of moringa oil can encourage establishment of cottage industries that would produce soap, pomade, perfume etc., thus creating employment and income sources for our unemployed youths.

Figure: 3a: Researcher evaluating growth potential *of experimented Moringa plant in UKZN*

Figure 3b: Moringa plant experimented at UKZN

Durban Research flowered after three to four months (4-5 m height)

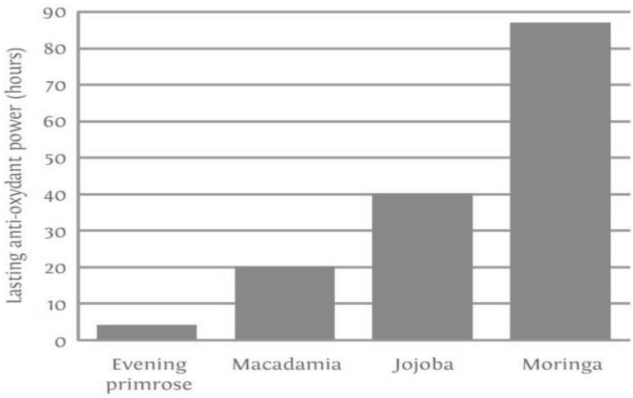

Figure 4: Moringa's anti-oxidative power over time *with other vegetable oils*

1.5 Moringa as a source of biogas

Moringa plants (approximately 30 days old) were milled together with water. The fibre was separated by filtration through a mesh with 5mm pores and the liquid fraction produced was then added to a biogas reactor. It was observed that with an average of 5.7g of volatile solids added, gas production was 580 litres of gas per 1kg of volatile solids. The average methane content of the gas was 81% (Makkar and Becker, 1996); Menke *et al.,* 1979). Harnessing this approach in moringa can go a long way in making cooking gas available and affordable in Nigeria. This will help to reduce the overdependence on crude oil as the only source of gas. The matured moringa seed is about 40% oil, with excellent quality (73% oleic acid) for cooking. This oil contains approximately 13% saturated fatty acids and 82% unsaturated fatty acids and has little tendency to deteriorate and become rancid and sticky [14, 15]. Simple techniques have been developed for moringa seed extraction. Once the oil is extracted the press cake contains about 60% protein and can be used as fertilizer. The seeds are round with a brownish semi-permeable seed hull. The hull itself has three white wings that run from top to bottom at 120-degree intervals. Each tree can produce between 15,000 and 25,000 seeds/year. The average weight per seed is 0.3g and the kernel to hull ratio is 75:25 [11, 18].

1.6 Industrial uses of *Moringa* Oil

The oil content of de-hulled seed (kernel) is approximately 42%. The oil is brilliant yellow. It is used as a lubricant for fine machinery such as timepieces because it has little tendency to deteriorate and become rancid and sticky [2426] [27. It is also useful as vegetable cooking oil. The oil is known for its capacity to absorb and retain volatile substances and is therefore valuable in the perfumery industry for stabilizing scents. The free fatty acid content varies from 0.5 to 3%. The seed oil of *Moringa* contains approximately 13%

saturated fatty acids and 82% unsaturated fatty acids. It has a particularly high level of oleic acid (70%). Other vegetable oils normally contain only about 40% oleic acid [27].

1.7 Moringa oleifera as Bio-Diesel/Bio-Fuels

Bio-diesel is a substitute for or an additive to diesel fuel that is derived from the oils and fats of plants like sunflower, cereal or Jatropha and provides power similar to conventional diesel fuels and help reduce the countries dependence on foreign oil imports and reduce global warming. United States has plugged the Philippine wonder plant,

"malunggay" as a source of biofuel. The malunggay is popularly cultivated in the country as background vegetable and as border trees and is the most useful plant that ever existed on planet earth.

A good source of biofuel was discovered in Moringa by the North America biofuel Inc. (NABI), which has tapped Moringa oil as potential raw material for biodiesel production. At present there are 165 marketing companies using soya bean oil as biodiesel raw materials in the U.S. it is anticipated that in 50 years from now, Japan and Korea will be the biggest markets of Moringa oil, because of its numerous autonomies that are using biodiesels. *Moringa* as biodiesel will help the country in solving the problem of climatic change caused by conventional fuels, because it burns smoke-free. It will also elevate the living conditions of the poor, because Moringa usage requires no big budgets.

1.8 Moringa oleifera in Industrial Gases and Hydrocarbon Production

High quality activated carbon can be prepared from the waste husks of Moringa. Steam activated husks exhibited a well-developed microspore volume of $0.57cm^3g^-1$ and a corresponding apparent surfaces area $734m^2g^-1$ as determined by $BETN_2$ adsorption hysteresis. In an assessment of aqueous phase adsorptive performance, activated Moringa carbon was found to be comparable to commercial powdered activated water treatment carbons (PACS). After the extraction of oil from Moringa, the remnant of the seed cake to the extent of 22 – 38.5% can be used for both domestic and industrial proposes, with the Moringa leaf biogas reactor, producing up to 580 litres of gas (81% methane) with an average fed of 5.7g of volatile solids from juvenile Moringa plants. This is a good alternative to fuel wood in place of cutting down trees that leads to deforestation. Also, foliar spray, with an extract from juvenile Moringa leaves, contains a cytokine type hormone. *Moringa* seeds contains between 30 - 42 % oil and the press cake obtained as a by- product of oil extraction process contains a high level of protein [14]. The oil is valued for culinary and cosmetic purposes, contains 60 -75% oleic acid and is comparable to olive oil in taste and cooking characteristics and have high antioxidant content which makes it slow to go rancid [22].

1.9 Processes involved in converting *Moringa oleifera* into Bio-Diesel

The process of converting vegetable oil into biodiesel fuel is called "Transesterification" and is less complex than it sounds. Chemically transesterification means taking a triglyceride molecule or a complex fatty acid to neutralize the free fatty acids, removing the glycerin and creating alcohol esters. This is accomplished by mixing methanol with sodium hydro acid. This liquid is then mixed into the vegetable oil and after the mixture has settled, glycerin is left on the bottom and methyl esters or biodiesel is left on top and washed and filtered. The final product, bio-diesel fuel when used will burn up to 75% cleaner than mineral oil diesel fuel. 241. The free fatly acid for Moringa was found to be 0.6%. The optimum production parameters determined experimentally was found to be 1.0wt% catalyst amount, 30wt% methanol amount, 60^OC reaction temperature, 400rpm agitation rate and 60min reaction time. With these optimal conditions, the conversion efficiency was 82%. This oil can be used as it is crushed i.e. unrefined in engines of cars; It can be blended with normal diesel and used in cars and can be refined and sold as pure diesel d) It can be refined and exported as a clean fuel to any parts of the world. The oil is brilliant yellow and is useful as lubricant for fine machinery, such as time pieces because of its little tendency to deteriorate and become sticky [20-22 ,27]. *Moringa* oil has the ability to absorb and retain volatile substances and is valuable in perfumery industry for scent stabilization. Processing Moringa seed to obtain finished products of the quality and at a price that can be marketed is not as straight forward as it sounds and requires sustained research efforts (Sutherland et al., 2001). Although there has been a lot of information on physical and chemical properties of Moringa oil, there exists a gap between scientific and practical research for development of economically competitive products. Research at UKZN is aimed at bridging this gap thus utilizing them directly in internal combustion engine while also highlighting the combustion characteristics of both the crude oil and the biodiesel. This paper is thus a preliminary study.

2. Materials/Methods

The analyses performed for this study are still ongoing and will be fully reported in subsequent publications. This preliminary study and review is to access the potential and prospects within the community of South African Development Community (SADC). M. oleifera oilseeds did not require much processing before oil extraction as the seed/pods are not complex to handle. The oil content of the seeds and kernels was estimated by extraction using a soxhlet apparatus [13] and employing hexane (60-80ºC), petroleum ether and gasoline. The oilseed samples were dehusked and the kernels pulverized into fine particles using a blender and dried in the auto clave oven at temperature above 100ºC to remove moisture and traces of other volatiles. Approximately 100 g of ground seed sample was weighed using analytical weighing balance, introduced into a 150 ml thimble and covered with cotton wool.

The thimble was placed into the thimble holder of the Soxhlet extractor, and the apparatus comprised of 200 ml round bottom flask containing 200 ml of the hexane, thimble unit, and condenser assembled. The Soxhlet flask was heated to evaporate and reflux the solvent through the sample. Hexane gasoline and petroleum ether vapors were cooled by tap water entering the condenser at temperature lower than 30ºC. The extraction process was conducted for 8 h in triplicate runs. After extraction, solvents were separated from oil using rotary evaporator for concentration. Concentrated oil was placed into an oven (WTB binder, Germany) at 105ºC for 1 h to remove any remaining solvent and water. The round bottom flask containing the oil was cooled to room temperature and weighed to obtain the weight of the extracted oil using the recommended equation. Moringa seed has a fairly soft kernel, so the oil can be extracted by hand using a screw press (also known as a "spindle" or "bridge" press). The seed is first crushed, 10% by volume of water is added, followed by gentle heating over a low fire for 10-15 minutes, taking care not to burn the seed. One such test yielded 2.6 liters of oil from 11 kg of kernels.

Once the best processing conditions are worked out, an extraction efficiency of 65% could probably be expected. The crude Oil samples produced were taken for various oil analyses for its potentials and for production of biodiesel via transesterification reaction. It is intended in the wilder research to experiment on pyrolysis. Moisture and ash were determined according to standard methods [10]. Extractives were determined gravimetrically after Soxhlet extraction with 96% (v/v) ethanol during 24 h. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were determined using the detergent methods [11].

2.1 Ranking of Moringa Oil

Ranking of the plants for vegetable oil production potential is usually performed using the Multicriteria Decision Analysis using five criteria, namely: oil content, type of extraction methods, solvent of extraction, seed yield per hectare, harvesting requirements, and seed preparation before oil expression. Each criterion was given a normalized weight between 0 for the least important and 1 for the most important criterion.

Oil content and seed/nut acreage yield are important criteria in determining the quantity of vegetable oil production, hence were assigned the highest weight of 0.33 each. Harvesting and seed/nut preparation which contributes to investment and operational cost were assigned weights of 0.14 and 0.2, respectively. Weights were multiplied by corresponding scores ranging between 0 for lowest and 10 for highest level to obtain weighted scores. The values of the scores were determined. Scores for oil content was given a score value of 10 for oil content greater than 30%,while other oil content scores were computed as a fraction of a percent of oil content divided by 30.

2.2 Chemical Analysis of the oil

The extracted oil from the seed was analyzed for chemo-physical properties of iodine number, acid value, free fatty acid, peroxide value, saponification value and ester value using standard procedure as recommended by the American Oil Analytical chemists (AOAC and Pearson). Other important chemo-physical properties such the density, specific gravity, refractory index, cetane number and index, fatty acid composition was also analyzed some will be reported in this study and others in subsequent papers as research is still ongoing. Emissions of Moringa during engine combustion and gaseous emissions in comparison with conventional diesel and result of blends are still at different WIP stages. Statistical Analysis: relevant descriptive and inferential statistics were employed for various comparisons and correlations with the studies of other authors.

2.3 Production method

The measured amount of Moringa oleifera oil in a beaker (in this study 100 g of oil was used for each of the experiments) was heated to a desired temperature on a hot plate. The required amount of sodium and potassium hydroxide catalysts were poured into a beaker containing a corresponding amount of methanol and allowed to mix for a while. After the oil temperature reached the desired point, the prepared sodium hydroxide and potassium hydroxide–methanol solution was added to the oil, taking this moment as the starting time of the reaction. When the reaction reached the preset reaction time, heating and stirring were stopped. All the products of the experiments in this study were allowed to settle overnight to enhance separation. Two distinct liquid phases were formed during separation, with the crude methyl ester phase at the top and the denser glycerol phase at the bottom. The bottom glycerine was removed while the crude Moringa oleifera methyl esters layer at the top was then separated using separatory funnel, washed with warm de-ionized water at between 80 to 1000ºC repeatedly until the water became clear. The excess methanol, other impurities like lecithin, phospholipids and water in the ester phase were then removed by heating the product to above 100ºC and kept constant at this temperature for a while. The Moringa biodiesel was therefore produced and ready for comprehensive biodiesel analysis in accordance with ASTM, EN and SANS.

2.4 Chromatographic Analysis (GC-MS)

The analysis of biodiesel products was conducted by a Varian Gas Chromatography apparatus (Model Number CP3400) equipped with an auto sampler (model number CP3800). A HT 5 Poly-siloxane coated column of length (30 m), i.d. (0.3 mm) and film thickness (0.53 lm) was used. The oven temperature was kept at 90ºC for 1 min, increased at 15 C/min up to 230ºC and held for 2 min and then ramped at 50ºC/min up to 380ºC where it was held for 2 min. The injector temperature was started at 90ºC and ramped up to 380ºC at a rate of 50 C/min while the detector temperature was maintained at 380ºC throughout the reaction. The weighed mass of the sample, placed into a clean reaction vial, 4 ml in size, was dissolved with hexane and further made up to 2 ml before injecting 0.5 ml onto the GC. Calibration standards were prepared from a methyl esters solution with a known concentration, and subsequently the standards were used to plot a calibration curve which was used in the determination of the methyl esters [23].

3. Results and Discussion

The results so far carried in the study shows crude Moringa oil preliminary properties which include some chemo-physical properties that are very determinant in its characteristics as a feedstock for biodiesel fuel and blends for engine utilization; when the standard of these properties are met with ASTM, ENS and SANS platforms, other analysis follow for proper characterization. The properties include specific gravity, saponification value, fatty acid composition, acid value/free fatty acid (FFA) profile, viscosity and others. These are represented in Table 1. Like could be observed, oleic acid is very prominent in the fatty acid profile (74.0%). From Table 1, it is possible to observe that 19% of the oil is composed of saturated fatty acids and 81% by unsaturated fatty acids, predominantly containing one double bond (78.0% of oleic acid) which is quite desirable as biodiesel. These results agree with those reported by Rachid et al. [23] and Ashraf and Gilani [28] and the small differences can be related to the variations in the provenance of seed collection and seed variety. The low percentage of linoleic acid and the absence of linolenic acid make it advantageous for better oxidative stability which is found repository in Moringa oil and biodiesel [13, 19-20]. The fatty ester profile generally agrees with general report from other authors who had ventured into the study. Moringa oleifera oil contains quite an insignificant amount of polyunsaturated fatty acid methyl esters (C18:2 and C18:3), which is really a biodiesel asset because there will be high atomization during combustion, lower viscosity and little or no buildup of noxious emission and soot formation will be quite minimal. In general, the fatty acid composition of M. oleifera oil is superior to that of other common vegetable oils used as biodiesel feedstocks even Jatropha. Oils with high oleic acid content are being desired which would give biodiesel fuels a reasonable balance or compromise of fuel properties.

Considering that the other saturated fatty acid methyl esters (C20:0 and C22:0) in Moringa biodiesel as well as C22:1 likely have high cetane numbers, the high cetane number of Moringa biodiesel therefore becomes anticipated. Moringa biodiesel appears to be a biodiesel fuel with one of the highest cetane numbers ever reported for a biodiesel fuel. M. oleifera-derived biodiesel easily meets the minimum cetane number requirements in both the ASTM D6751 and EN 14214 biodiesel standards, which are 47 and 51, respectively. The oxidative stability of MOME is considerably reduced compared to the parent oil (Table 1 and 2).

Possible explanations are that the antioxidants naturally present in M. oleifera oil and viscosity as obtainable in any feedstock are deactivated or thinned down through the transesterification process and/or removed by the subsequent purification or separation procedures. There is no doubt that Moringa is a potentially valuable oil seed crop and that its oil appears to be a viable and promissory feedstock for biodiesel production.

Other properties also examined in comparison with ASTM and EN were flash point, pour point, cloud point, kinematic viscosity, cetane number by estimation and density. Table 2 shows these parameters in reference to the standards. The results obtained were quite very interesting as they virtually fell within the standards if not all. The high flashpoint temperature of the Moringa biodiesel is a beneficial safety feature, as this fuel can safely be stored at room temperature.

Table 1: Moringa Crude oil preliminary properties

Chemo-physical properties	**Values Obtained**
Specific gravity	0.906
Saponification value	192.4
Acid value	2.45 mg KOH/g
Free fatty acid (FFA)	0.6 %
Dynamics viscosity @ 20ºC	92.6 cP
Fatty Acid Composition	
Palmitic acid (C16: 0)	7.4
Palmitoleic acid (C16: 1)	1.4
Stearic acid (C18: 0)	5.5
Oleic acid (C18: 1 cis)	74.0
Linoleic acid (C18: 2 cis)	6.2
Linolenic acid (C18: 3 n3)	trace
Arachidic acid (C20: 1)	2.6
Behenic acid (C20: 0)	4.5

These results are in agreement with those reported for other vegetable oils that exhibit typical fatty acid composition [14-20] [24] [26] [27]. These are presented in comparison to ASTM D6751 and EN 14214 specifications (Table 2).

Table 2: Preliminary Chemo-physical Properties of Moringa Biodiesel (B100 methyl-ester)

Some Chemo-physical Properties	Value /Unit	ASTM D6751-02 standards	EN 14214/ SANS
Flash point	204ºC	130 min	120 min
Acid Value	0.012 mg KOH/g	< 0.80	< 0.50
Pour Point	3.5ºC	Not specified	Not specified
Cloud point	12ºC	Not specified	Not specified
Kinematic Viscosity @40ºC	4.89cSt or mm^2/s	1.9 – 6.0	3.5 – 5.0
Cetane number	63	> 47	> 51
Density/Specific gravity @ 20ºC	$0.88g/m^3$	0.850 – 1.0	0.86 – 0.90
Carbon residue	0.050 wt%	0.050	

The density met acceptable ranges (EN 14214 specification) and the kinematic viscosity value is higher than the maximum value specified (EN 14214 and ASTM D6751). After extraction, Moringa seeds were found to contain above 40% w/w oil using different solvents (Table 4) which is not in disagreement with the reports of other authors [14-19]. Figure 5 is the FTIR chromatogram result that shows the bond stability of the oil and its methyl ester (biodiesel) with high oxidative stability.

Table 3: Analysis of the Press cakes of Moringa

Chemical Content	Moringa Press cakes (%w/w)
Ash	6.2 ± 0.06
Cellulose	5.0
ADF	7.6
Hemicelluloses	0.5
NDF	9.7
Lignin	2.4
Protein	69.3 ± 0.22

Table 4: Percentage crude oil yields and Biodiesel from different solvents

20.00

	Hexane	Petroleum Ether	Gasoline	NaOH (catalyst)	KOH (catalyst)
Moringa Crude Oil	38%	40%	43%	-	-
Moringa Biodiesel (B100)	-	-	-	85%	74%

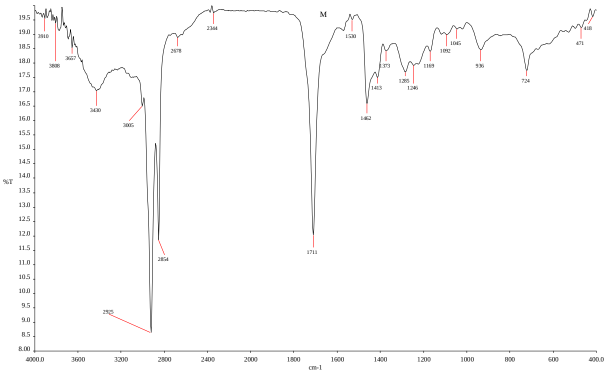

Figure 5: Fourier Transform Infrared Spectroscopy chromatogram of Moringa

4 Conclusions

Moringa oil was obtained from the kernels with good yield (above 40 %) from different solvents employed opening the possibility of commercial application, provided that siviculturist studies, involving plant breeding, taxonomy and development of proper propagation system, are conducted in order to improve the seed production and possibly reduce gestation. The crude oil was transesterified and based on the preliminary results obtained in this study, regarding fuel properties, it is evident suggest that the feedstock has huge prospect and potential as biofuel in diesel engines and also the possibility of blending with AGO and hybridization with other feedstock for better quality will be an added vista which the comprehensive study is ongoing at the University of KwaZulu-Natal.

Moringa oleifera oil is a promising source for biodiesel production and is currently not used for its edibility. The purpose of the present study was to evaluate this oil as a potential raw material for biodiesel production which has been achieved. Moringa oleifera oil was chemically converted via an alkaline transesterification process using NaOH and KOH as catalysts. There was proper separation of glycerine from the methyl esters. Fuel Properties met minimum requirements of both the ASTM, SANS and ENS. Further investigation of MOME could be broadened by the examination of different catalyst types and its impact on the engine performance and exhaust emissions in respect to other biodiesels which is ongoing. It is noteworthy too to state that the most highlighted property of biodiesel from Moringa oil is the high cetane number of approximately 64 – 68. This is no doubt the highest ever reported for a biodiesel fuel. The oxidative stability of the oil and biodiesel fuel is also incomparably higher than other biodiesel fuels/feedstock. Thus, biodiesel derived from M. oleifera oil is an acceptable substitute for conventional diesel (AGO) also when compared to biodiesel fuels from another feedstock.

Acknowledgment

The study was conducted by the Green Energy Solution (GES) Research Group, Discipline of
Mechanical Engineering, University of KwaZulu-Natal, Howard College, Durban, Republic of South Africa. The authors are grateful to the University.
DVC (Research) of the University of KwaZulu-Natal on behalf of Centre for Engineering Postgraduate Studies (CEPS).

References

[1] Okafor, J.C. Overview on potentials of medicinal plants in health and wealth creation in Nigeria. Invited paper presented at one day sensitization workshop/exhibitions on Moringa and other medicinal plants holding on 13th Nov. 2008 at the main auditorium, Nnamdi Azikiwe University, Awka. 2008.

[2] Kamuze, G. "Moringa" cure – all Tree that became mother's best friend NABDA /UNU-INRA (2004) special Training Programme on: Plant Taxonomy, systematic & Indigenous Bioresources management jointly organized by the National Biotechnology Development Agency (NABDA) and the United

Nations University Tokyo, Japan Institute for natural Resources in Africa (UNUINRA)at the southeast zonal Biotechnology centre University of Nigeria, Nsukka. 15. Nov – 3rd Dec 2004. 164pp. 2003.

[3] ANSTISS Investment Group. Moringa: The miracle Tree in Mozambique.

[4] Okafor J.C. & Caldecott, T.O. (1990) using Biodiversity and Agroforestry system for Conservation in Nigeria. Proceedings of the international conference on Tropical Biodiversity. “In Harmony with Nature” 12 – 16 June 1990, Kuala Lampour, Malaysia Pg 608-628. 1990.

[5] Okafor J.C. & Ham, R Identification, Utilization and Conservation of medicinal plants in southeastern Nigeria. Issues in African Biodiversity. The biodiversity support Program. Number 3, July 1999. 7pp.

[6] Irvine, F.R. Woody Plants of Ghana with special reference to their uses: London, Oxford University. Press Pp 53 – 54. 1961

[7] Okafor J.C. & Lamb, A. Fruit trees: diversity and conservation strategies. In Tropical tress: the potential for domestication and the rebuilding of forest resources Edited by RRB. Leaky & A.C. Newton. London: HMSC pp.34 – 41. 1994

[8] Ozumba, N.A. Moringa oleifera – a multipurpose tree. Intermediate Technology Food Chain 18 July 1996 Pp 3-5. 1996

[9] Ozumba, N.A. Moringa oleifera. A review of its medicinal and other uses. Institute of Development Studies, university of Nigeria, Enugu Campus. 35pp. 2008

[10] Shepherd, G & Okafor J.C. Cameroon forest Management and Regeneration Project: Socio – economic survey. Overseas Development Institute, London. Report A. December 1991 – January 1992. [11] Makkar, H.P S. & Becker, K. Nutrients and antiquality factors in different morphological parts of the *Moringa oleifera* tree. J*ournal of Agricultural Science*, Cambridge 128,331-322. 1997

[12] Anwar, F., Latif, S., Ashrat, M., and Gilani, H. A. Moringa oleifera: A food plant with multiple medicinal uses. Phytother. Res. 21:17-25. 2007 [13] Anwar, F. and Rashid, U. Physio-chemical characteristics of *Moringa oleifera* seeds and seed oil from a wild provenance of Pak. Pak. J. Bot. 39: 1443-1453. 2007,

[14] Foidl, N; H.P.S Makkar and Beckar, K. The potential of *moringa oleifera* for agricultural and industrial uses. In what development potential for moringa products. October 20th – November 2nd2001. Dar Es Salam. 20pp. 2001

[15] Price, M.L. The Moringa tree: Echo Technical Note. 2007

[16] Lalas, S. and Tsaknis, J. (2002). Characterization of Moringa oleifera seed oil Variety ‘Periyakulam 1’. J. Food Compstn. Analy. 13:65-77.

[17] Li, S., Zhang, H., and Xue. T. A new method for the determination of acid value of vegetable oils. Eur. J. Lipid. Sci. Tech. 109:1088-1094. 2007. [18] Mohammed, A.S., Lai, O.M., Muhammad, S.K.S., Long, K. and Ghazali, H.M. *Moringa oleifera*, potentially a New Source of oleic acid type oil for Malaysia. *In* Investing in Innovation. 3: 137-140. 208. 2003

[19] Anwar, F and Rashid, U. Physio- Chemical characteristics of *moringa oleifera* seeds and seed oil from a wild provenance of Pakistan. Pak. J. Bot. 39(5): 1443-1453. 2007

[20] Lalas, S and Tsaknis, J. Characterization of *moringa oleifera* seed oil variety Periyakulam 1. Journal of Food Composition and Analysis 15: 65-77. 2002

[21] Mbeza, H.E; Pratt, M Chawala and Nyirenda, K. Optimization of oil extraction from *moringa oleifera* and Jatropha curcus using Ram and spindle presses. Regional Agroforestry Conference, May 20-24. Pretoria South Africa. 2002

[22] Radovich, T (2010) *Moringa Oleifera*. Specialty Crops for pacific Island Agro forestry. http://agroforestry.net/scps. accessed 28th March 2010.

[23] Rashid, U; F. Anwar, B.R Moses and Knothe, G. *Moringa oleifera* oil: Possible source of biodiesel. Bioresource Technology 99: 8175-8179. 2008.

[24] Rashid, U. Farooq Anwar, Muhammad Ashraf, Muhammad Saleem, Yusup, S. Application of response surface methodology for optimizing transesterification of Moringa oleifera oil: Biodiesel production. Energy Conversion and Management 52: 3034–3042. 2011.

[25] Kafuku, G., Mbarawa, M. Alkaline catalyzed biodiesel production from moringa oleifera oil with optimized production parameters. Applied Energy 87: 2561–2565. 2010.

[26] da Silva, J.P.V, Tatiana M. Serra, Marcelo Gossmann, Carlos R. Wolf, Mario R. Meneghetti, Meneghetti, S.M.P. Moringa oleifera oil: Studies of characterization and biodiesel production. Biomass and Bioenergy 34: 1527-1530. 2010.

[27] Ramachandran, C; K.V Peter and Gopalakrishnan, P.K. Drumstick (*moringa Oleifera*): a multipurpose Indian vegetable. Economic Botany 34: 276-283. 1980. [28] Ashraf F, Gilani SR. Fatty acids in Moringa oleifera oil. *J Chem Soc Pakistan* 2007 29: 343345.