Energies **2010**, *3*, 607–618; doi:10.3390/en3040607

OPEN ACCESS

energies

ISSN 1996-1073

www.mdpi.com/journal/energies

Article

Investigating "Egusi" (*Citrullus Colocynthis* L.) Seed Oil as Potential Biodiesel Feedstock

Solomon Giwa [1], Luqman Chuah Abdullah [2,3] and Nor Mariah Adam [1,*]

[1] Alternative and Renewable Energy Laboratory, Institute of Advanced Technology (ITMA)/Mechanical and Manufacturing Engineering Department, Faculty of Engineering, Universiti Putra Malaysia, 43400, Serdang Darul Ehsan, Selangor, Malaysia; E-Mail: sologiwa2002@yahoo.com

[2] Chemical and Environmental Engineering Department, Faculty of Engineering, Universiti Putra Malaysia, 43400, Serdang Darul Ehsan, Selangor, Malaysia; E-Mail: chuah@eng.upm.edu.my

[3] Laboratory of Biopolymer and Derivatives, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400, Serdang Darul Ehsan, Selangor, Malaysia;

* Author to whom correspondence should be addressed; E-Mail: mariah@eng.upm.edu.my; Tel.: +60-3-89466345; Fax: +60-3-86567122.

Received: 22 October 2009; in revised form: 31 December 2009 / Accepted: 15 January 2010 / Published: 30 March 2010

Abstract: Biodiesel's acceptance as a substitute for fossil-derived diesel has grown the world over. However, the food-fuel debate over conventional vegetable oils has rekindled research interest in exploring lesser known and minor oil crops. In this work, egusi melon seed oil was studied for the first time as a potential feedstock for biodiesel production. Crude egusi melon seed oil was transesterified using sodium methoxide as the catalyst at 60 °C and an oil/methanol ratio of 1:6 to produce its corresponding methyl esters. Egusi melon oil methyl ester (EMOME) yield was 82%. Gas chromatographic analysis of EMOME showed that it was composed mainly of palmitic, stearic, oleic, linoleic and linolenic esters, which is similar to the profile of sunflower, soybean and safflower oil. All the measured fuel properties of EMOME satisfied both the ASTM D6751 and the EN 14214 biodiesel standards. Fuel properties of EMOME were essentially identical with those of soybean, safflower and sunflower biodiesel. Remarkably, the kinematic viscosity of EMOME was measured to be 3.83 mm^2/s, a value lower than most biodiesel fuels reported in the literature. The potential of egusi melon seed oil as a biodiesel feedstock is clearly presented in this study.

Keywords: biodiesel; fuel properties; egusi; melon seed oil; crude oil

1. Introduction

The major sources of the world's energy needs are petroleum, coal and natural gases which are fossil-derived and non renewable. The world, at large, depends on petroleum as the energy source for the transportation sector. Scarcity of traditional petroleum fuels, its over-dependence by nations, increasing emissions of combustion-generated pollutants and their increasing costs have made renewable energy sources more attractive. The world petroleum reserves are finite in nature and declining fast, the production of oil will eventually slow down and plateau.

For over a century now, the use of vegetable oils such as soybean, palm, sunflower, peanut and olive oil as fuel substitutes for fossil-based diesel has been around, with the inventor of the diesel engine Rudolph Diesel being the first to test peanut oil in his compression ignition engine. Biodiesel, defined as the mono alkyl esters of long chain fatty acids obtained from renewable feedstock, such as vegetable oil or animal fats, for use in compression ignition engines [1]. Recently, biodiesel has become more attractive because it is environmentally friendly, derived from renewable resources, biodegradable and non-toxic in nature. It can also be produced from any material that contains fatty acids, either linked to other molecules or present as free fatty acids [2]. Thus, various vegetable fats and oils, animal fats, waste greases, and edible oil processing wastes can all be used as feedstocks for biodiesel production [2]. Biodiesel which has been accepted as a possible substitute of conventional diesel fuel is produced from triglycerides by transesterification with methanol/ethanol and mainly in the presence of a catalyst.

Owing to their availability, various oils have been in use in different countries as feedstocks for biodiesel production. Rapeseed and sunflower oils in Europe, soybean oil in U.S., palm oil in Malaysia and Indonesia and coconut oil in Philippines are being used for biodiesel production. Also, the jatropha tree (*Jatropha curcas*), karanja (*Pongamia pinnata*) and mahua (*M. indica*) are used as major biodiesel fuel sources in India [3]. In spite of this, biodiesel production from conventional vegetable oils (soybean, sunflower, safflower, palm, rapeseed *etc.*) has progressively stressed food uses, price, production and availability of these oils [4]. Consequently, this has ignited the search for additional regional biodiesel raw materials. With 350 oil-bearing crops having been identified, recent studies on biodiesel from less common or unconventional oils include *Moringa oleifera* [4], *Michelia champaca* and *Garcinia indica* [5], pumpkin [6], sea mango [7] and desert date [8] oils.

Cucurbitaceae is a large plant family which consists of nearly 100 genera and 750 species [9]. This plant family is known for its great genetic diversity and widespread adaptation which includes tropical and subtropical regions, arid deserts and temperate locations [10]. Curcubits are known for their high protein and oil content. Seeds of cucurbits are sources of oils and protein with about 50% oil and up to 35 % protein [11]. Specifically for these reasons they are cultivated and consumed world over. "Egusi" (*Citrullus colocynthis* L.) belongs to the species of the genus *Citrullus* of cucurbitaceae family, which usually consists of a large number of varieties that are generally known as melons [12]. Egusi (*Citrullus colocynthis* L.) is among the 300 species of melon found in tropical Africa and it is

cultivated for its seeds, which are rich in oil (53%) and protein (28%) [13]. The regions of its cultivation are Middle East, West African (Nigeria, Ghana, Togo, Benin) and other African countries for the food in the seeds and as a crop inter-planted with maize, cassava and yam [14]. In Nigeria only, ‘‘egusi’’ is cultivated over an area of 361,000 ha with a production figure of 347,000 tonnes (as seeds) in 2002 [15]. It is used both as condiment and thickener in Nigerian local soup, and the industrial scale production of the oil yet to be utilized despite the huge potential [14]. Various studies have reported predominantly high linoleic fatty acid content in egusi melon seed oils [10,14,16]. Due to the unsaturated fatty acid composition of its oil, it was reported to resemble that of safflower [16], corn, cottonseed, sunflower, soybean and sesame oil [10].

Throughout this study, “egusi” (*Citrullus colocynthis* L.) has been referred to as “egusi melon” for proper identification and consistency with the literature. The main objective of the present study was to investigate the use of egusi melon seed oil (EMSO) as a potential feedstock for biodiesel production. The fuel properties of the egusi melon oil methyl ester (EMOME) were determined and compared with biodiesel fuels from conventional vegetable oils.

2. Experimental Section

2.1. Materials

Crude egusi melon seed oil was purchased from a local store in Lafenwa, Abeokuta, Ogun State, Nigeria and imported to Malaysia for this study. The oil was filtered using a double layer of cheesecloth to remove solid particles present in it. The moisture was removed by oven drying at 110 °C for 1 h [17] and it was stored at 4–8 °C until used. Certified methanol (99.8% purity) and sodium methoxide (95%) were purchased from MERCK (Malaysia). A FAME mixture of fatty acid methyl esters (≥99.5%) and heptadecanoic methyl ester (≥99.5 %) used as reference and internal standards, respectively, were purchased from Kromtek (Malaysia) Sdn. Bhd. Biodiesel D6584 kit (containing reference standard solution: triolein, diolein, monoolein, glycerol and the two internal standards: butanetriol, and tricaprin of >99% purity) was also purchased from Kromtek (Malaysia) Sdn. Bhd. In addition, derivatization grade *N*-methyl-*N*-(trimethylsilyl) trifluoroacetamide (MSTFA) was purchased from Kromtek (Malaysia) Sdn. Bhd. *n*-Heptane (≥96%) and heptane used as solvents for GC analyses were purchased from MERCK (Malaysia). All the chemicals used were analytical reagent grade.

2.2. Analysis of egusi melon seed oil

Prior to transesterification, oil quality properties of the crude egusi melon seed oil were determined. These properties included saponification value, density, kinematic viscosity, iodine value, free fatty acid, acid value, colour (using Lovibond tintometer) and higher heating value (HHV). The oil properties were analyzed in accordance with Palm Oil Research Institute of Malaysia (PORIM) standard test methods for oil analysis as described in PORIM, 1995 with the exception of the HHV. ASTM D240 standard method was used in determining the HHV of the oil. All experiments were run in triplicate and mean values were reported.

2.3. Transesterification

Oven drying (pretreatment) of the crude egusi melon seed oil was repeated before transesterification. The transesterification of the oil was carried out under ambient pressure in a 1 L two-necked round bottom reactor equipped with a thermometer, a hot plate with magnetic stirrer, and a reflux condenser. The reactor was initially filled with 100 g of crude egusi melon seed oil, which was preheated to the desired temperature before starting the reaction. The reaction was carried out at 60 °C for 1 h with 1 wt% of $NaOCH_3$ and methanol-to-oil molar ratio of 6:1 [4]. In order to maintain the catalytic activity, a mixture of $NaOCH_3$ and methanol was freshly prepared to avoid methanol losses and prevent moisture build-up. This was mixed until the complete dissolution of the catalyst. The solution was added into the reactor and stirred at 360 rpm. The reaction time started as soon as the catalyst/methanol solution was added to the reactor. On completion of the reaction, the resulting product was cooled to room temperature without any agitation and transferred to a separatory funnel for glycerol and methyl ester separation. It was left overnight to allow separation by gravity. After the two phases have separated, the upper phase was collected and the excess alcohol in it removed using a vacuum evaporator operated at 80 °C. The resulting methyl ester obtained was purified by successive washing with warm deionized water to remove residual catalyst, glycerol, methanol and soap. A small quantity of sulphuric acid was used in the second washing to neutralize remaining soaps and catalyst. Finally, the egusi melon oil methyl ester was dried over anhydrous sodium sulphate to remove residual water. A filtration process followed to remove solid traces. This experiment was run in triplicate and mean value was reported:

$$\text{Yield} = \frac{\text{Weight of methyl ester produced, } W_1}{\text{Weight of oil used in reaction, } W_2} \times 100\% \quad (1)$$

2.4. Gas chromatography analysis

A Shimadzu (Kyoto, Japan) gas chromatograph, model 17-A, coupled with a flame ionization detector (FID) was used to analyze the fatty acid composition and ester content of egusi melon oil biodiesel obtained from the transesterification reaction. This was carried out according to the EN 14103 standard method. Separation was done with a DB-WAX capillary column (30 m × 0.25 mm, I.D. × 0.25 μm; J & W Scientific, Folsom, CA, USA). Helium was used as the carrier gas. Oven temperature at 120 °C was initially held for 1 min and then increased to 220 °C (held 15 min) at a rate of 4 °C/min. Injector and detector were set at 230 °C and 250 °C, respectively. A sample volume of 1.0 μL was injected using split mode (split ratio of 1:100). FAMEs were identified by comparing their relative and absolute retention times with those of authentic standards. Heptadecanoic acid (C17:0) was used as an internal standard. The FA composition was reported as a relative percentage of the total peak area. The ester content was evaluated from the following equation:

$$Y_{ester}(\%) = \frac{\sum A - A_s}{A_s} \times \frac{C_s V_s}{m} \times 100 \quad (2)$$

where ∑A is the summation of the GC peak areas of methyl esters (C14:0–C24:1), A_s is the GC peak area of methyl heptadecanoate, C_s is the concentration of STD solution, V_s is volume of STD solution, and m is the amount of sample.

The free and total glycerol present in egusi melon oil biodiesel was analyzed using gas chromatography in accordance with the ASTM D6584 standard method. The same GC used above was equipped with a capillary column of DB-5HT (15 m × 0.25 mm, I.D. × 0.10 μm; J & W Scientific: Folsom, CA, USA) and the analysis was performed using the procedure reported in [18].

2.5. Biodiesel property determination

Fuel properties of EMOME, such as density (ASTM D4052), kinematic viscosity (ASTM D445), flash point (ASTM D93), cloud point (ASTM D2500), acid value (EN 14104), oxidation stability (EN 14112) and HHV (ASTM D240), were measured according to relevant biodiesel test methods. The cetane number of EMOME was evaluated using empirical formula reported in the literature [19] as given below. In addition, cetane number of individual methyl ester was obtained from a published work [20] to enhance the use of the formula:

$$CN = X_{ME}\ (wt.\%) \times CN_{ME} \quad (3)$$

where CN, is the cetane number of the biodiesel, X_{ME} is the weight percentage of each methyl ester and CN_{ME} is the cetane number of individual methyl ester. All tests were run in triplicate and mean values were reported

3. Results and Discussion

3.1. Physicochemical properties of egusi melon seed oil

Freshly extracted crude oil from egusi melon seed was used in this study. The oil was extracted using a manually-operated mechanical press. The quality of egusi melon seed oil (EMSO) was expressed in terms of selected physicochemical properties, such as acid value, saponification value, density *etc.*, as shown in Table 1. The acid value and the saponification value of the oil were 0.98 and 204.44 mg KOH/g, respectively. With acid value of 0.98 mg KOH/g corresponding to 0.49% free fatty acid (FFA) content, transesterification of the oil was conducted directly (using a single-stage reaction process) [6]. Moreover, it has been reported that <0.5% FFA content is required for successful transesterification to avoid soap formation resulting from high free fatty acid [3,6]. The kinematic viscosity of crude egusi melon seed oil was 31.52 mm^2/s (Table 1), which was similar to that reported for safflower and soybean oil [21]. The density and HHV of the oil were determined to be 905.3 kg/m^3 and 39.37 MJ/kg, respectively. These results are well within the range reported for conventional vegetable oils [21]. All the properties of EMSO (except the HHV) generally were in agreement with previous studies [22-24].

3.2. Fatty ester composition

The fatty ester profile of EMOME, as determined by gas chromatography is provided in Table 2. It was found that EMSO composed of six fatty acids: palmitic, palmitoleic, stearic, oleic, linoleic and linolenic acids. The fatty acid composition of the EMSO was in close agreement with previous studies [22,23,25]. Of the six fatty acids, linoleic acid is the most prevalent with the value of 61.41%. The total saturated and unsaturated fatty acid contents of the seed oil were 20.2 and 79.8%, respectively. Palmitic acid (10.48%) was the predominant saturated fatty acid. For comparison purpose, the fatty acid compositions of rapeseed, soybean, palm, safflower, sunflower and jatropha oils are listed in Table 2. As shown in Table 2, the fatty acid profile of EMSO (especially in terms of total unsaturation) was similar to that of soybean, sunflower, jatropha and safflower oils but not palm oil. EMSO has a fatty acid profile which resembles those of some conventional oils (soybean, rapeseed, sunflower, cotton, corn) with oleic and linoleic acids being the major acids [26] which signifies its probable use as biodiesel production feedstock in terms of its chemical composition and oil properties.

Table 1. Physicochemical properties of egusi melon seed oil.

Parameter	**Egusi**
Iodine value (g I_2/100g)	114.46
Density at 15 °C (kg/m^3)	905.3
Kinematic viscosity at 40 °C (mm^2/s)	31.52
Saponification value (mg KOH/g)	204.44
Acid value (mg KOH/g)	0.98
Free fatty acid (%)	0.49
Caloric value (MJ/kg)	39.37
Colour	5Y + 0.4R
Ave. Molecular weight (g)	874

3.3. Biodiesel yield

Biodiesel yield estimation was done after the separation and purification of the transesterified product. The 82 percent yield of EMSO synthesized was calculated according to Equation 1. Naturally occurring vegetable oils and animal fats are known to contain tocopherols, phospholipids, steryl glucosides, chlorophyll, fat soluble vitamins, and hydrocarbons. Some of these impurities are insoluble and can be removed by filtration while others are soluble. The insoluble part can only be removed by different refining processes. It has been reported that the reduced yields in biodiesel production with raw oils could be as a result of the presence of solids and extraneous material in the oils [20]. The negative impact impurities present in oil have on ester yield has been stressed [27]. Furthermore, under the same reaction conditions, 67 to 84% ester conversion can be obtained using crude vegetable oils, compared with 94 to 97% when using refined oils [21]. Previous studies on the transesterification of crude oils of tobacco seed [26], karanja [28], sesame [30] and rice bran [42] reported 84, 86, 74

and 83.31% ester yield, respectively. Conclusively, the yield obtained in this present work is within the range of values achieved in previous studies.

3.4. Fuel properties of egusi melon oil methyl ester

The fatty acid composition of the raw materials employed in transesterification process dictates, to a large extent, the fuel properties of biodiesel produced. Different feedstocks utilized in biodiesel production certainly have different chemical compositions and undeniably have different fuel properties. The fuel properties of the EMOME determined in this study are presented in Table 3. For comparison purposes, fuel properties of methyl esters of soybean (SOME), sunflower (SUOME) and safflower (SAOME) are provided (Table 3).

Table 2. Fatty acid compositions (wt%) of vegetable oils and egusi melon oil methyl esters.

Fatty acid	Class	Palm[a]	Jatropha[b]	Rape[a]	Soybean[a]	Safflower[a]	Sunflower[a]	Egusi
Caprylic	C8:0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Capric	C10:0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Lauric	C12:0	0.9	0.0	0.0	0.0	0.0	0.0	0.0
Myristic	C14:0	1.3	0.0	0.0	0.1	0.1	0.1	0.0
Palmitic	C16:0	43.9	18.22	2.7	10.3	6.6	6.0	10.48
Palmitoleic	C16:1	0.0	0.0	0.0	0.0	0.0	0.0	0.06
Stearic	C18:0	4.9	5.14	2.8	4.7	3.3	5.9	9.72
Oleic	C18:1	39.0	28.46	21.9	22.5	14.4	16.0	17.95
Linoleic	C18:2	9.5	48.18	13.1	54.1	75.5	71.4	61.41
Linolenic	C18:3	0.3	0.0	8.6	8.3	0.1	0.6	0.38
Erucic	C22:1	0.0	0.0	50.9	0.0	0.0	0.0	0.0
Total saturated		51.20	23.36	5.50	15.10	10.00	12.00	20.20
Total unsaturated		48.80	76.64	94.50	84.90	90.00	88.00	79.80

[a]:[37]; [b]:[41].

Density is an important parameter for diesel fuel injection systems. It is the weight of a unit volume of fluid. A higher density for biodiesel results in the delivery of a slightly greater mass of fuel since fuel injection equipment operates on a volume metering system. The density of EMOME was found to be 883 kg/m^3. This result fits into the limits specified by EN 14214 standard. Moreover, the density of EMOME was observed to be in good agreement with that of conventional methyl esters (SOME, SUOME and SAOME) as shown in Table 3 for comparison.

Kinematic viscosity is a very important fuel property and it represents the flow characteristics of fuel. One of the reasons why biodiesel is used as an alternative fuel instead of pure vegetable oils or animal fats is as a result of its reduced viscosity which enhances fuel flow characteristics. In addition, kinematic viscosity is an important parameter regarding fuel atomization and combustion as well as fuel distribution. The kinematic viscosity of EMOME measured at 40 °C was 3.83 mm^2/s, which conformed to both biodiesel standards (Table 3). As seen in Table 3, the kinematic viscosity of egusi melon oil biodiesel is lower than SOME, SUOME and SAOME. Most studies reported kinematic

viscosities of 4.0 mm^2/s and above for biodiesel fuels [19,31,32]. However, kinematic viscosities of 3.5 mm^2/s (at 40 °C) and 3.6 mm^2/s (at 37.8 °C) were published for tobacco seed oil biodiesel [26] and babassu oil biodiesel [21], respectively. Kinematic viscosity increases with FA chain length and with increasing degree of saturation of either the fatty acid or alcohol moiety in a fatty ester [33].

Table 3. Fuel properties of egusi melon oil biodiesel and other biodiesel fuels.

Property	Unit	Limits		SOME	SUOME	SAOME	EMOME
		ASTM D6751	EN 14214				
Ester content	% (mol/mol)	-	96.5 min	96.9[a]	97.2[a]	97.67[c]	96.78
Density; 15 °C	kg/m^3	-	860–900	885[d]	884[b]	874[c]	883
Kinematic viscosity; 40 °C	mm^2/s	1.9–6.0	3.5–5.0	4.2[a]	4.85[b]	4.29[c]	3.83
Flash point	ºC	130 min	120 min	171[a]	168[b]	176[c]	142
Cloud point	°C	Report	-	1[d]	1[b]	2[c]	0.5
Acid value	mg KOH/g	0.5 max	0.50 max	0.14[a]	0.4[b]	0.28[c]	0.19
Linolenic acid content	% (mol/mol)	-	12.0 max	6.3[a]	0.2[a]	-	0.38
Higher heating value	MJ/kg	-	-	41.28[e]	45.5[b]	45.21[c]	39.97
Oxidation number	h	3 min	6 min	1.3[a]	1.96[b]	-	1.41
Cetane number		47 min	51 min	49[a]	55[b]	52.32[c]	53.66*
Free glycerol	wt.%	0.02 max	0.02 max	0.07[a]	0.015[f]	0.016	0.011
Total glycerol	wt.%	0.24 max	0.25 max	0.00[a]	0.201[f]	0.225[c]	0.192

[a]:[19]; [b]:[29]; [c]:[36]; [d]:[38]; [e]:[39]; [f]:[40] *: Empirically determined

HHV is the amount of heat released during the combustion of one gram of fuel to produce CO_2 and H_2O at its initial temperature and pressure. HHV, or heat of combustion, was determined according to ASTM D240 standard method, but it is not specified in both ASTM D6751 and EN 14214 standards. As shown in Table 3, HHV of EMOME was measured to be 39.97 MJ/kg, this is well within the range reported for SOME, SUOME and SAOME. HHV of most biodiesel fuels are in the range of 39 and 41 MJ/kg [3] and a value of 39.8 MJ/kg was reported for tobacco seed oil biodiesel [26].

The flash point of a fuel is the temperature at which it will ignite when exposed to a flame. The flash point of biodiesel is higher than diesel fuel, which makes it safer for transportation purpose. The biodiesel produced from EMSO had a flash point of 142 °C. This result meets the minimum specifications of both standards (Table 3). However, this value is slightly less than those of SOME, SUOME and SAOME used in the present study for comparison as provided in Table 3. Moreover, flash points of 135, 160, 180, 141 and 163 °C have been reported for palm, soybean, sunflower, pongamia and jatropha biodiesel, respectively [31].

Cloud point is the temperature at which wax first becomes visible to the naked eye when the fuel is cooled. At temperatures below the cloud point, larger crystals fuse together and form agglomerations that eventually become extensive enough to prevent pouring of the fluid and consequently affecting the performance of fuel lines, fuel pumps and injectors. The low-temperature behavior of biodiesel is significantly influenced by molecular structure. Low-temperature properties depend mostly on the saturated ester and the effect of unsaturated ester composition can be negligible [34]. The cloud point of EMOME was found to be 0.5 °C, similar to that of SOME and SUOME (Table 3), though the

smallest numerically. According to ASTM D6751 and EN 14214 standards, no limit is specified for cloud point. This may probably be due to the fact that the climate conditions world over vary to a great extent, thus affecting the needs of biodiesel consumers in each particular region.

Acid value is a measure of the FFA content in the biodiesel and is measured as the milligram of KOH required to neutralize the FFAs in 1 gram of the sample. The acid value of egusi melon oil biodiesel produced in the present work was 0.19 mg of KOH/g. Both standards specified a maximum limit of 0.5 mg of KOH/g for biodiesel. The acid value of EMOME satisfies this specification and hence, is an indication of good biodiesel quality. The acid value of biodiesel fuel depends on the type of feedstock and how well the fuel is processed. A high acid value makes the fuel prone to polymerization and also acts as catalyst for hydrolysis.

The ester content of EMOME (96.78%) is slightly higher than the minimum limit of 96.5% specified by EN 14214 standard and consequently meets the biodiesel specification. This result shows the purity of EMOME and the completeness of the alkaline transesterification reaction. The ester content of egusi melon oil biodiesel agrees well with those of SOME, SUOME and SAOME (Table 3). Ramos *et al*. [19] reported ester content of between 96.9–99.8% for biodiesel from ten different vegetable oils.

Linolenic acid content of EMOME was determined to be 0.38%. This value is well within the EN 14214 specification since it is far lower than the 12% (maximum) it prescribed. In addition, the biodiesel produced from EMSO met the free (0.011%) and total (0.192%) glycerol specifications set in both EN 14214 and ASTM D6751 biodiesel standards.

The percentage and nature of fatty acids contained in vegetable oils depends on the plant species. The fatty acid profile of vegetable oil is a primary factor influencing oxidation, since the rate of oxidation depends on the number and position of double bonds. To substantiate this, oxidation stability has been reported to decrease with increase in polyunsaturated methyl esters such as linoleic and linolenic esters [35]. Oxidation stability of a fuel is a measure of its shelf life. Oxidation stability of EMOME as measured by the Rancimat method (EN 14112), gave an induction period (IP) of 1.41 h. The value was lower than the minimum IP specified in EN 14214 (6 h) and ASTM D6751 (3 h), which can be attributed to the relatively high linoleic acid (C18:2) content of EMOME (Table 2). This result is in agreement with those of SOME, and SUOME (Table 3) which have relatively high linoleic acid and polyunsaturated fatty acid contents (Table 2). In addition, oxidative rates of oleic, linoleic, linolenic have been reported in the ratio of 1:12:25 [32] and further justified the low value of the oxidation stability of EMOME. In order to improve the stability, treatment with antioxidant additives (phenolic and aminic) may restore the oxidative stability of EMOME to an acceptable level.

Cetane number is related to the ignition properties and is a key indicator of fuel quality in diesel engines. Cetane number affects the engine performance parameters like combustion, stability, driveability, white smoke, noise and emissions of CO and HC. Higher cetane number signifies better ignition properties. Biodiesel has higher cetane number than conventional diesel fuel which results in higher combustion efficiency. The cetane number of EMOME was evaluated by using Equation (2) and found to be 53.66. This empirical value satisfies both biodiesel standards and agrees well with cetane number of SOME, SUOME and SAOME as provided (Table 3). Although with similar fatty acid profile, cetane number of EMOME is well in range with those of SOME, SUOME and SAOME.

Cetane number depends largely on chain length and degree of unsaturation and is higher in compounds with higher saturated fatty acid [33].

4. Conclusions

EMSO was transesterified using methanol in the presence of sodium methoxide to produce EMOME. All the determined biodiesel fuel properties and qualities of EMOME conformed to EN 14214 and ASTM D6751 standards with the exception of oxidation stability. The oxidative stability of biodiesel synthesized from egusi melon oil was unsatisfactory in line with ASTM D6751 and EN 14214 as a result of its high polyunsaturated fatty acid content. Fuel properties and fatty acid composition of egusi melon oil biodiesel were found to be synonymous to those of soybean, sunflower and safflower biodiesel which have been well established and widely published. It is worth mentioning that EMOME has a remarkably low kinematic viscosity compared to most biodiesel. This present study has justified the use of EMSO as a potential raw material for biodiesel production**.**

Acknowledgements

I thereby acknowledge Universiti Putra Malaysia (UPM) for the Graduate Research Fellowship (GRF) awarded during the course of this work. My sincerest and deep gratitude goes to the management and staff of Institute of Advanced Technology (ITMA) of UPM for the facilities and cooperation enjoyed. Special thanks to Queen Omolara Giwa for her love and moral support during the period of carrying out this research.

References and Notes

1. Murugesan, A.; Umarani, C.; Chinnusamy, T.; Krishnan, M.; Subramanian, R.; Neduzchezhain, N. Production and analysis of bio-diesel from non-edible oils–A review. *Renew. Sustain. Energy Rev*. **2009**, *13*, 825–834.
2. Balat, M.; Balat, H.A critical review of biodiesel as vehicular fuel. *Energ. Conv. Mgmt*. **2009**, *49*, 2727–2741.
3. Demirbas, A. Progress and recent trends in biodiesel fuels. *Renew. Sustain. Energy Rev*. **2009**, *50*, 14–34.
4. Rashid, U.; Answar, F.; Moser, B.R.; Knothe, G. *Moringa oleifera* oil: A possible source ofbiodiesel. *Bioresour. Technol*. **2008**, *99*, 8175–8179.
5. Hosamani, K.M.; Hiremath, V.B.; Keri, R.S. Renewable energy sources from *Michelia champaca* and *Garcinia indica* seed oils: A rich source of oil. *Biom. Bioenerg.* **2009**, *33*, 267–270.
6. Schinas, P.; Karavalakis, G.; Davaris, C.; Anastopoulos, G.; Karonis, D.; Zannikos, F.; Stournas, S.; Lois, E. Pumpkin (*Cucurbita pepo* L.) seed oil as an alternative feedstock for the production of biodiesel in Greece. *Biomass Bioenerg.* **2009**, *33*, 44–49.
7. Kansedo, J.; Lee, K.T.; Bhatia, S. *Cerbera odollam* (sea mango) oil as a promising non-edible feedstock for biodiesel production. *Fuel* **2009**, *88*, 1148–1150.

8. Chapagain, B.P.; Yehoshua, Y.; Wiesman, Z. Desert date (*balanites aegypytiaca*) as an arid sustainable bioresource for biodiesel. *Bioresour. Technol*. **2009**, *100*, 1221–1226.
9. Ng, T.J. New opportunities in the cucurbitaceae. In *New Crops*, 1st ed.; Janick, J., Simon, J.E., Eds.; Wiley: New York, NY, USA, 1993; pp. 538–546.
10. Oluba, M.O.; Ogunlowo, Y.R.; Ojieh, G.C.; Adebisi, K.E.; Eidangbe, G.O.; Isiosio, I.O. Physicochemical properties and fatty acid composition of *citrullus lanatus* (Egusi melon) seed oil. *J. Biol. Sci*. **2008**, *8*, 814–817.
11. Achu, M.B.; Fokou, E.; Tchiegang, C.; Fotso, M.; Tchouanguep, F.M. Nutritive value of some cucurbitaceae oilseeds from different regions in Cameroon. *Afr. J. Biotechnol*. **2005**, *11*, 1329–1334.
12. Mabaleha, M.B.; Mitei, Y.C.; Yeboah, S.O. A comparative study of the properties of selected melon seed oils as potential candidates for development into commercial edible vegetable oil. *J. Am. Oil Chem. Soc.* **2007**, *84*, 31–36.
13. Ntui, V.O.; Thirukkumaran, G.; Iioka, S.; Mii, M. Efficient plant regeneration via organogenesis in ‘‘egusi’’ melon (*Colocynthis citrullus* L.). *Scientia Hort.* **2009**, *119*, 397–402.
14. Uruakpa, F.O.; Aluko, R.E. Heat-induced gelation of whole egusi (*Colocynthis citrullus* L.) seeds. *Food Chem.* **2004**, *87*, 349–354.
15. Federal Ministry of Agriculture and Rural Development. Agricultural outlook in Nigeria. In *Proceedings of the Nigeria National Crop Outlook Conference*, Kano State, Nigeria, May 2005. Available online: http://www.mistowa.org/files/CAFSTON/AGRICULTURAL%20OUTLOOK%20-%20PRSD.pdf (accessed on 26 December 2009).
16. Yaniv, Z.; Shabelsky, E.; Schafferman, D. Colocynth: Potential arid land oilseed from an ancient cucurbit. *In Perspectives on New Crops and New Uses*, 1st Edition.; Janick, J., Eds.; ASHS Press: Alexandria, VA, USA, 1999; pp. 257–261.
17. Patil, P.D.; Deng, S. Optimization of biodiesel production from edible and non-edible vegetable oils. *Fuel* **2009**, *88*, 1302–1306.
18. Akgün, N.; Iscan, E. Effects of process variables for biodiesel production by transesterification. *Eur. J. Lipid Sci. Technol*. **2007**, *109*, 486–492.
19. Ramos, M.J.; Fernandez, C.M.; Casas, A.; Rodriguez, L.; Perez, A. Influence of fatty acid composition of raw materials on biodiesel properties. *Bioresour. Technol*. **2009**, *100*, 261–268.
20. Moser, B.R. Biodiesel production, properties, and feedstocks. *In Vitro Cell. Dev. Biol.-Plant* **2009**, *45*, 229–266.
21. Srivastava, A.; Prasad, R. Triglycerides-based diesel fuels. *Renew. Sustain. Energy Rev*. **2000**, *4*, 111–33.
22. Milovanović, M.; Pićurić-Jovanović, K. Characteristics and composition of melon seed oil. *J. Agric. Sci*. **2005**, *50*, 41–49.
23. Al-Khalifa, A.S. Physicochemical characteristics, fatty acid composition, and lipoxygenase activity of crude pumpkin and melon seeds. *J. Agric. Food Chem*. **1996**, *44*, 964–966.
24. Kamel, B.S.; Dawson, H.; Kakuda, Y. Characteristics and composition of melon and grape seed oils and cakes. *J. Am. Oil Chem. Soc*. **1995**, *62*, 881–883.
25. Akoh, C.C.; Nwosu, C.V. Fatty acid composition of melon seed oil lipids and phospholipids. *J. Am. Oil Chem. Soc.* **1992**, *69*, 314–316.

26. Usta, N. Use of tobacco seed oil methyl ester in a turbocharged indirect injection diesel engine. *Biomass Bioenerg.* **2005**, *28*, 77–86.
27. Freedman, B.; Pryde, E.; Mounts, T. Variables affecting the yields of fatty esters from transesterified vegetable oils. *J. Am. Oil Chem. Soc*. **1984**, *61*, 1638–1643.
28. Srivastava, P.K.; Verma, M. Methyl ester of karanja oil as alternative renewable source energy. *Fuel* **2008**, *87*, 1673–1677.
29. Rashid, U.; Anwar, F.; Arif, M. Optimization of base catalytic methanolysis of sunflower (*Helianthus annuus*) seed oil for biodiesel production by using response surface methodology. *Ind. Eng. Chem. Res*. **2009**, *48*, 1719–1726.
30. Saydut, A.; Duz, M.Z.; Kaya, C.; Kafadar, A.B.; Hamamci, C. Transesterified sesame (*Sesamum indicum* L.) seed oil as a biodiesel fuel. *Bioresour. Technol*. **2008**, *99*, 6656–6660.
31. Sarin, R.; Sharma, M.; Sinharay, S.; Malhotra, R.K. Jatropha-palm biodiesel blends: An optimum mix for Asia. *Fuel* **2007**, *86*, 1365–1371.
32. Chakraborty, M.; Baruah, D.C.; Konwer, D. Investigation of terminalia (*Terminalia belerica* Robx.) seed oil as prospective biodiesel source for North-East India. *Fuel Process. Technol*. **2009**, *90*, 1435–1441.
33. Knothe, G.; Matheaus, A.C.; Ryan, T.W. Cetane numbers of branched and straight-chain fatty esters determined in an ignition quality tester. *Fuel* **2003**, *82*, 971–975.
34. Imahara, H.; Minami, E.; Saka, S. Thermodynamic study on cloud point of biodiesel with its fatty acid composition. *Fuel* **2006**, *85*, 1666–1670.
35. McCormick, R.L.; Ratcliff, M.; Moens, L.; Lawrence, R. Several factors affecting the stability of biodiesel in standard accelerated tests. *Fuel Process. Technol*. **2007**, *88*, 651–657.
36. Rashid, U.; Anwar, F. Production of biodiesel through base-catalyzed transesterification of safflower oil using an optimized protocol. *Energy Fuels* **2008**, *22*, 1306–1312.
37. Allen, C.A.W.; Watts, K.C.; Ackman, R.G.; Pegg, M.J. Predicting the viscosity of biodiesel fuels from their fatty acid ester composition. *Fuel* **1999**, *78*, 1319–1326.
38. Bajpai, D.; Tyagi, V.K. Biodiesel: Source, production, composition, properties and its benefits. *J. Oleo Sci*. **2006**, *55*, 487–502.
39. Demirbas, A. Relationships derived from physical properties of vegetable oil and biodiesel fuels. *Fuel* **2008**, *87*, 1743–1748.
40. Rashid, U.; Anwar, F.; Moser, B.R.; Ashraf, S. Production of sunflower oil methyl esters by optimized alkali-catalyzed methanolysis. *Biomass Bioenergy* **2008**, *32*, 1202–1205.
41. El-Diwani, G.; Attia, N.K.; Hawash, S.I. Development and evaluation of biodiesel fuel and by-products from jatropha oil. *Int. J. Environ. Sci. Technol*. **2009**, *6*, 219–224.
42. Rashid, U.; Anwar, F.; Ansari, T.M.; Arif, M.; Ahmad, M. Optimization of alkaline transesterification of rice bran oil for biodiesel production using response surface methodology. *J. Chem. Technol. Biotechnol*. **2009**, *84*, 1364–1370.