Ultrasound Assisted Biodiesel Production from Eruca Sativa as an Indigenous Species in Iran

Ahmad Hajinezhad*‡, Seyed Sina Hosseini*

*Department of Renewable Energies and Environment, Faculty of New Sciences and Technologies, University of Tehran, Tehran, Iran

(hajinezhad@ut.ac.ir; hosseini.sina@ut.ac.ir)

‡Corresponding Author; Ahmad Hajinezhad, Faculty of New Sciences and Technologies, University of Tehran, Tehran, Iran, Tel: +98 912 839 6794,

Fax: +98218396794, hajinezhad@ut.ac.ir

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Abstract- In this study Eruca sativa was used as an industrial and least desirable edible source for biodiesel production. To this aim, fatty acid methyl esters C14, C16:0, C16:1, C18:0, C18:1, C18:1c, C18:2, C18:3c, C18:3, C18:3t, C20, C20:1, C22, C22:1, C24 and C24:1 were determined by Gas Chromatography (GC) and BF_3 method and the results showed that C18:1 has the highest proportion (55.91%) of methyl ester in this oil. Also, kinematic and dynamic viscosity, density, amount of free fatty acids, soap and acid values of Eruca sativa oil were measured as 33.885 (mP.s), 37.06 (mm^2/s), 0.915 (g/cm^2), 0.42%, 187.857 (mg KOH/1gOil) and 1.533 (mg KOH/1gOil), respectively. Biodiesel from Eruca sativa oil was obtained by a basic transesterification method using an ultrasound device under ultrasonic amplitude of 70%, power of 172.32 W, 24 kHz, and 9 min at 45 °C, with methanol/oil ratio of 6 and 1% potassium hydroxide as catalyst. Then, according to the EN and ASTM standards, the quality of biodiesel such as flash point, density at 15 °C, kinematic viscosity at 40 °C, acid value, cetane number, and water content determined as 164 °C, 882 (g/m^3), 4.8531 (mm^2/s), 0.27 (mg KOH/1gOil), 54 and 9.17 (mg/kg), respectively. The effect of fatty acid profile of Eruca Sativa oil on physicochemical properties of methyl ester was profoundly discussed and compared according to the suitable distribution suggested by several studies. The results showed that there is a high performance of methyl ester production (95.61% conversion) from Eruca sativa oil using ultrasound technology.

Keywords Biodiesel, Fatty Acid Profile, Transesterification, Ultrasound, Eruca Sativa.

1. Introduction

Energy as an inseparable part of life is vital for humankind routines and it is expected in the near future, energy supply issues will be one of the most important challenges that countries might involve [1]. In recent years, global energy demand has drastically increased owing to industrial development and ongoing population growth as well as growing life standards [2], which necessitates the development of new energy resources to secure the growing energy demand in many developing and developed countries [3]. Notably, the majority of the world's energy demand is met by fast depleting non-renewable fossil fuels such as petroleum, natural gas, and coal. From another standpoint, the vast utilization of fossil fuels has brought about many public health and environmental problems [4]. In order to alleviate the foreboding environmental problems and to cope the increasing energy demands, incessantly and sufficiently, it is essential to develop and utilize the alternative renewable biofuels [5].

Amongst several available biofuels, biodiesel has been verified as a potential renewable and environmentally benign alternative for conventional mineral diesel fuels, possessing promising characteristics i.e. non-toxic, high cetane number, biodegradable, aromatic free and clean burning fuel that can be used in prevalent diesel engines with no modification [6]. Biodiesel is mono mono-alkyl esters of long chain fatty acids, which satisfies some standards and can be produced through the transesterification process of triglycerides with alcohols in the presence of several acidic or alkaline catalysts [7]. Due to the immiscible nature of oil and alcohols as the reactants of the transesterification reaction, the process takes place in a two-phase interfacial system and naturally at a slow rate, which necessitates the presence of severe mixing

to ensure a significant surface contact. Nevertheless, the drastic energy requirements and likewise longer reaction time are the major problems regarding mechanical agitation. Ultrasound technique has been reported as a novel and effective tool for biodiesel production, since higher conversion rates and shorter reaction times in comparison with conventional mechanical agitation methods can be achieved by minimizing the mass transfer limitations along with cavitation phenomenon [8,9].

Recently, a considerable amount of studies has been carried out on biodiesel production from various novel and new emerging feedstocks as well as yield enhancement, its characteristics and engine emissions. For instance, reference [10] studied the performance and emission characteristics of diesel engine fueled by biodiesel prepared from the raw oils of Jatropha, Moringa and Palm. In another study, the production of biodiesel from Pongamia and the evaluation of properties of various blends of biodiesel in diesel engine were performed by [11] and the results showed that biodiesel can be replaced with diesel as a source of fuel in near future. Reference [12] surveyed Kernel characteristics, oil contents, fatty acid compositions and biodiesel properties in developing Siberian apricot (Prunus sibirica L.) seeds and they reported that the Siberian apricot seeds harvested after 8 weeks after anthesis may be suitable for producing biodiesel. Moreover, Norouzak (Salvia lerifolia) seed oil was introduced as an indigenous source of biodiesel production in Iran and its characteristics were assessed and discussed by [13]. Reference [14] performed the production of algal biodiesel from three processes namely flask-magnetic stirrer, Soxhlet apparatus and ultrasonication technique; and based on the results, ultrasonication has been proved to be suitable among the other techniques. Biodiesel production from common edible oils such as sunflower oil is roughly criticized due to the worldwide food crisis [15]. However, the application of other non-edible or least-desirable edible oil feedstock for biodiesel production could be of great interest and their potential should be assessed and scrutinized in depth. Least-desirable edible Eruca Sativa seed oil, as an indigenous crop in Iran, is expected to be a potential feedstock for biodiesel production, due to its satisfactory oil contents (35%) and low price; as well as its outstanding resistance to harsh conditions, outlines its promising capability among various biodiesel feedstocks [16]. To the best of authors' knowledge, no survey could be found in the published literature on ultrasound assisted biodiesel production from Eruca Sativa as an indigenous special in Iran. To this aim, this study was conducted to present the potential of least-desirable Eruca Sativa seed oil for biodiesel production as well as its fuel properties were computed and compared with EN and ASTM standards.

2. Materials and Methods

2.1. Materials

In Iran many recent studies have focused on biodiesel production from various sources such as sunflower, soybean, safflower, canola, rapeseed and palm oils [17]. Not only such resources haven't noticeable area under cultivation over Iran, they are also considered to possess a significant portion through the edible oil supply chain over the country. Moreover, due to the limited acreage of these crops, the production costs could increase significantly. Therefore, despite their positive environmental effects, replacement of such products has a negative impact on the edible oil supply chain and it isn't economically and environmentally competitive with fossil fuel resources. Eruca Sativa oil from Brassica family with undesirable and displeasing taste which is not appropriate for eating, has a great potential for biodiesel production due to its satisfactory oil contents (35%) and low price, as well as its outstanding resistance to poor rainfall and harsh soil conditions outlines its promising capability among various biodiesel feedstocks [16]. In the present study, the least desirable Eruca sativa oil is collected from Golestan province, Iran. Figure 1 (a), (b) and (c) show the Eruca Sativa plant, flower and seed, respectively. Methanol (99.9 % purity, Merck), potassium hydroxide (Merck) were used as the reactants for the transesterification reaction. Moreover, n-hexane (Merck), methyl Heptadecanoate (Fluka), were used for fatty acid methyl ester analysis.

(a) (b) (c)

Fig. 1. Eruca Sativa plant and seed

2.2. Oil Preparation

Prior to the biodiesel production procedure, the crude oil should be prepared. Free fatty acids, water and sediment contents are the main factors having adverse impacts on biodiesel yield. The presence of free fatty acids leads to the saponification reaction and catalyzer utilization so that brings about additional catalyzer necessities and separation problems. Water contents cause the hydrolysis of triglycerides to glycerol and free fatty acids which in turn reduces the yield of methyl ester production. In order to purify the oil and remove free fatty acid contents, the oil was heated indirectly to 80^{o}C inside an Erlenmeyer flask, 1% wt. phosphoric acid (85% purity) was added to the oil and then flask contents were stirred using a magnetic stirrer at 45 rpm for 5 minutes. Afterwards, 16 degree Baumé sodium hydroxide was added to the above-mentioned mixture and finally the soapy phase was removed after saponification of free fatty acids by sodium hydroxide. It is worth noting that the applied sodium hydroxide value was obtained using titration of Eruca Sativa oil. To remove water contents, the oil was heated to 100 ^{o}C and stirred for 1 hour using a magnetic stirrer. As well as, for sediment and particle removal, the crude oil was filtered twice. The remaining oil

is the purified and removed free fatty acid and water oil which is suitable for transesterification procedure.

2.3. Oil Analyses

The fatty acid profile of Eruca Sativa oil was determined using gas chromatography and BF_3 method according to ISO 5509 standard. Moreover, the oil dynamic and kinematic viscosity at 40°C, density, free fatty acids amount, soap value and acidity of Eruca sativa oil were also measured. A viscometer device (Stabinger, SVM 3000) was applied to obtain kinematic and dynamic viscosity of the oil. Figure 2 (a) and (b) show the applied viscometer and GC devices, respectively. Also, in order to measure the density of Eruca Sativa oil, 1 ml of the oil was weighed and the process was replicated thrice and the average value was reported.

Water content of oil was determined by heating oil in the furnace and weighing the sample at the initial and final sates of heating process according to ISO 662 standard. This process was replicated thrice and the average value was reported. Also acid value (acidity) of Eruca Sativa oil was obtained by titrating Eruca Sativa oil by potassium hydroxide and calculating the weight (mg) of potassium hydroxide necessary to neutralize 1 (g) of the sample. The titration is the method of determining the concentration of free fatty acid by adding potassium hydroxide that reacts with it to an endpoint. The free fatty acid percentage was also calculated by titration procedure according to D5555-95 ASTM standard. To this aim, 28.2 grams of Eruca Sativa oil were mixed with 50 ml propanol alcohol and Phenolphthalein indicator (1%); the potassium hydroxide solution with normality of 0.1 was added to the sample drop by drop until a neutral situation (pink color) was established in 30 seconds and finally the free fatty acid percentage was calculated using the following equation:

$$\text{Free Fatty Acid (\%)} = \frac{28.2 \times \Gamma \times N}{\upsilon} \quad (1)$$

Where Γ and N stand for the volume (ml) and normality of potassium hydroxide solution, respectively, and υ is the weight of the oil sample (gr). It is worth noting that the 28.2 is the molar mass of oleic acid divided by ten.

(a) (b)

Fig. 2. The viscometer (a) and GC device (b) utilized in this study

Soap number represents the number of milligrams of potassium hydroxide required to saponify 1g of fatty acid. The saponification value provides an indication of the nature of the fatty acid constituent of fats and therefore, depends on the molecular weight of the fatty acid constituents. The higher the molecular weight, the smaller the number of fatty acids is contained per gram of fat hydrolyzed and consequently, the smaller the saponification number and vice versa. In order to measure the soap value, 1 g of Eruca Sativa oil was mixed with 25 milliliter of potassium hydroxide and ethanol solution (0.5 mole KOH/liter methanol) and then was heated at reflux for 60 min on a boiling water batch. Afterwards, the solution was cooled to the room temperature. After cooling, the excess KOH was titrated with 0.5 mole/liter hydrochloric acid solution. Phenolphthalein was used as indicator. Furthermore, a blank sample was prepared containing only the potassium hydroxide and ethanol solution. The difference between the blank and the test reading gives the number of milliliters of potassium hydroxide required to saponify 1g fat. The following equation was used to calculate soap number of oil:

$$S_N = \frac{(S-B) \times 0.5 \times 56.11}{W_{oil}} \quad (2)$$

Where S and B represent the ml of hydrochloric acid used for block and test, respectively, and W_{oil} is the weight of used oil.

2.4. Transesterification reaction of Erica Sativa oil

Transesterification is the process of exchanging the organic group of an ester with the organic group of an alcohol (usually ethanol and methanol). The reaction is catalyzed by the addition of an acid or base catalyst. In this study, a basic transesterification procedure was conducted for methyl ester production through a batch procedure using methanol alcohol and potassium hydroxide. A methanol to oil molar ration of 6 was utilized and 1% wt. of potassium hydroxide was used as catalyst from the total weight of the reactants. The transesterification reaction comprises of three consecutive reversible reactions as represented in Eqs. (3), (4) and (5) [18]. It is worth mentioning that excess alcohol (compared to stoichiometric value) is necessary to shift the reaction to methyl ester production due to the reversibility of transesterification reaction. The final products are methyl esters, glycerol, soap, catalyzer, as well as di- mono and tri-glycerides. Moreover, there are some unreacted alcohols within the reaction mixture which should be separated. At first step, methanol and potassium hydroxide were stirred using a magnetic stirrer until all of the catalyst dissolved in order to increase the contact level of catalyzer throughout the reactants. The solution of methanol and potassium hydroxide (potassium methoxide) was then added to Eruca Sativa oil and the temperature was raised to 45°C.

$$\text{Triglyceride} + \text{ROH} \leftrightharpoons \text{Diglyceride} + \text{RCOOR}_1 \quad (3)$$
$$\text{Diglyceride} + \text{ROH} \leftrightharpoons \text{Monoglyceride} + \text{RCOOR}_2 \quad (4)$$
$$\text{Monoglyceride} + \text{ROH} \leftrightharpoons \text{Glycerol} + \text{RCOOR}_3 \quad (5)$$

2.5. Ultrasound

The transesterification reaction was carried out in the presence of ultrasonic irradiation to intensify the reaction yield and reduce reaction completion time. To this aim, the digital ultrasound device model "Misonix Sonicator 4000" under the operational conditions at cycle setting amplitude of 70%, 45°C temperature during 9 minutes was used for the biodiesel production. In cycle setting of 70%, the oil and potassium methoxide mixture was sonicated for 0.7 s and then sonication halts for 0.3 s. The energy consumption and temperature changes through the reactants were monitored using Ultrasonic PC Control software. Recent studies propose that ultrasonic exposure is a novel, practical and efficient emulsification tool for the production of biodiesel, so that higher reaction yields and shorter completion times can be obtained by utilizing less catalyzer and energy compared to mechanical agitation. Ultrasound emitter was operated at 24 kHz with a power of 172.32 W at 70% cycle mode. Use of ultrasonic wave as a new technology to speed up transesterification reaction, increases reaction efficiency and reduces the amount of catalyst and energy required to produce biodiesel has been reported by several researchers. This would be due to the collapse of cavitation bubbles and the ultrasonic jet that impinges one liquid to another, disrupting the phase boundary thereby causing emulsification. The ultrasound in the chemical processes, enhances both the mass transfer and chemical reactions. It offers the potential for shorter reaction times, cheaper reagents and less extreme physical conditions leading to less expensive and smaller chemical plants.

2.6. Methyl ester analysis

The produced methyl ester from Eruca Sativa oil through the transesterification process catalyzed by potassium hydroxide in the presence of ultrasound was analyzed in order to determine its detailed characteristics and then was compared with characteristics of biodiesel produced from palm and Jatropha oils. To this aim, methyl ester conversion (%), dynamic viscosity (mP.s) at 40°C, kinematic viscosity (mm^3/s) at 40°C, density (kg/m^3) at 15°C, acid value, flashpoint and water content were determined, compared and conformed according to the relative standards. The viscosity of the methyl esters was determined at 40°C by means of Stabinger viscometer (SVM 3000). The following equation was applied to calculate biodiesel conversion (%):

$$\text{Conversion} = \frac{(\sum_i A_i) - A_{standard}}{A_{standard}} \times \frac{M_{standard}}{M_{biodiesel}} \times 100 \quad (6)$$

Where A_i is the area under the curve of ith relating peak, $A_{standard}$ is the area under the standard peak, $M_{standard}$ is the mass of methyl heptadecanoate as internal standard and $M_{biodiesel}$ is the mass of biodiesel sample.

The pour point for biodiesel can be determined by means of methods provided by ASTM D-97 pour point test, in which the pour point is obtained as that temperature at which oil ceases to flow when the sample is held at 90 degrees to the upright for five seconds. Also, in order to obtain the flashpoint of methyl ester, an automatic Pensky-Martens flashpoint analyzer equipment (model K71000) with closed cup was used, which conforms to the ASTM D93 and related specification for all biodiesels with flashpoints above 130°C. The fundament of measuring flashpoint is based on heating the biodiesel sample in a close vessel and recording the temperature when the sample starts to burn.

3. Results and Discussions

In this study Eruca sativa oil was used as an industrial and least desirable edible source of biodiesel using methanol as alcohol and potassium hydroxide as catalyzer by means of transesterification procedure under ultrasound irradiation. The physiochemical properties of Eruca Sativa oil and the related produced methyl ester were measured and profoundly discussed.

3.1. Eruca Sativa oil characteristics

Prior to transesterification process, the review of physicochemical characteristics of feedstocks can be helpful and interesting to assess the quality of the raw materials, mostly concerning the possible mechanism improvements and yield enhancement. Due to the fact that the properties of produced methyl ester strongly depend on feedstock features, the characteristics of Eruca Sativa oil i.e. dynamic and kinematic viscosity, density, FFA content, as well as acid and soap values were measured and compared with other biodiesel sources i.e. Palm and Jatropha oil as shown in Table 1.

According to Table 1, FFA content of Eruca Sativa oil was 0.42%. According to the literature [19], it is strictly essential that during the alkali-catalyzed transesterification process, the used feedstock should contain FFA less than 0.5%. The FFA can easily react with potassium hydroxide and form soap which is known as saponification process. The soap can hinder separation of the biodiesel from the glycerol. The presence of FFA causes alkali-catalyzer consumption and consequently necessitates additional catalyzer values for reaction completion which in turn brings about separation problems and extra costs.

Moreover, the acid value of Eruca Sativa oil was obtained as 1.533 mg KOH/1gOil. Interestingly, the acid value of Eruca Sativa oil was lower when compared to palm and Jatropha oils. The higher acid values can adversely affect the conversion of transesterification process and the quality of produced biodiesel.

Table 1. Oil characteristics of *Eruca Sativa, Palm and Jatropha*

Parameter	Unit	Eruca Sativa	Palm	Jatropha
Dynamic viscosity	mP.s	33.885	40.96	40.4

Kinematic viscosity	mm^2/s	37.06	31.8	34.1
Density	gr/cm^3	0.915	0.916-0.926	0.92
Molar mass	gr/mole	896.05	833.8	845.35
Soup value	mg/1gOil	187.857	188-201	195
FFA	%	0.42	0.1	0.1
Acid value	mg/1gOil	1.533	1.25	38.2

The dynamic and kinematic viscosity of Eruca Sativa oil at 40°C were obtained as 33.885 mP.s and 37.06 mm^2/s, respectively. Also, the density of the oil at 15°C was found to be 0.915 kg/cm^3. Experiments have proved the considerable dependence of mixing time and quality on viscosity and density differences between two immiscible liquids. The density of methanol as second reactant is 0.792 kg/cm^3. The lower the viscosity of oil, the higher is mixing quality and mass transfer between two immiscible phases i.e. oil and methanol which consequently causes high yield and better contact between reactants. Any differences in viscosity of two liquids lead to discontinuity of the velocity gradients at an inter-material surface, which may cause destabilization of laminar flow during mixing [20]. Considering the fact that the dynamic viscosity of methanol at 40 °C is 0.47 mP.s, there is a considerable difference between reactants' viscosities (0.47 vs 33.885 mP.s) which impedes proper mixing and mass transfer between two immiscible phases. Despite this, according to Table 1, the dynamic viscosity of Eruca Sativa oil was lower compared to palm and Jatropha oils representing its promising potential for biodiesel production according to better mixing and mass transfer.

3.2. Fatty acid profile of Eruca Sativa oil

One microliter of the prepared oil sample, was injected into the gas chromatography device and the fatty acid profile of Eruca Sativa oil was obtained after 30 minutes. The chromatogram of fatty acids is represented in Figure 3. Also, Table 2, tabulates the results of fatty acid profile of Eruca Sativa oil with corresponding fatty acid values and percentages in the oil obtained by gas chromatography (GC) and BF_3 methods. According to Table 2, C14, C16:0, C16:1, C18:0, C18:1, C18:1c, C18:2, C18:3c, C18:3, C18:3t, C20, C20:1, C22, C22:1, C24 and C24:1 were the main fatty acids within Eruca Sativa oil. It is apparent that Vaccenic acid (C18:1) had the highest proportion (55.91%) of fatty acids in the oil.

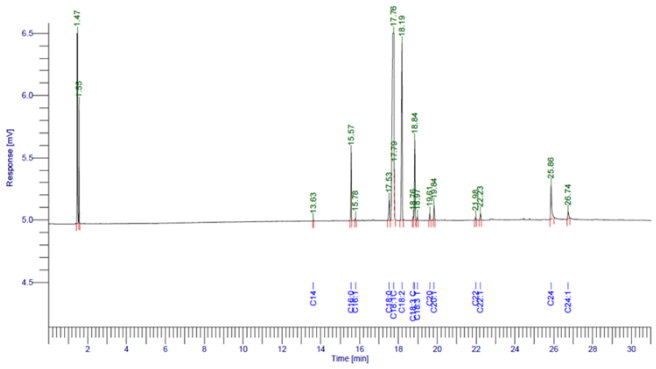

Fig. 3. Fatty acid profile of Eruca Sativa oil determined by GC

Moreover, Table 3 tabulates the divided distribution of saturated, unsaturated, monounsaturated and polyunsaturated as well as long (above 18 carbons), average (18 carbons) and short (under 18 carbons) chain fatty acids in Eruca Sativa oil. The composition of the biodiesel has significant influence on its quality. Nearly 88 percent of fatty acids were unsaturated and the rest (about 12 %) was saturated fatty acids. A saturated fatty acid is a type of fatty acids which have single bonds. Many health authorities advise that saturated fatty acids are a risk factor for cardiovascular disease in human. Moreover, studies have proven that NO_x emissions increase as the degree of unsaturation increase. Simply speaking, it is more desirable and suitable to have biodiesel with saturated or monounsaturated fatty acid methyl esters. The presence of polyunsaturated fatty esters is the cause of oxidative stability problems with biodiesel and the presence of higher amounts of saturated fatty esters is the cause of cold flow problems (in line with pour and cloud points) [21].

According to literature [22], it is declared that biodiesel with a high level of monounsaturated fatty acids may have excellent characteristics regarding ignition quality as well as fuel stability and viscosity. In this case, based on the data provided in Table 3, 74.67% of fatty acids in Eruca Sativa oil is saturated and monounsaturated fatty acids which represents its desirability for biodiesel production.

Table 2. Fatty acid contents of Eruca Sativa oil obtained by GC

Name of fatty acid	g/mole	Formula	(%)
Nervonic acid (C24:1)	366	$C_{24}H_{46}O_2$	0.95
Lignoceric acid (C24)	368	$C_{24}H_{48}O_2$	4.6
Erucic acid (C22:1)	338	$C_{22}H_{42}O_2$	3.1
Behenic acid (C22)	340	$C_{22}H_{44}O_2$	0.27
Paullinic acid (C20:1)	310	$C_{20}H_{38}O_2$	1.23
Arachidic acid (C20)	328	$C_{20}H_{40}O_2$	0.59
α-Linolenic acid (C18:3)	278	$C_{18}H_{30}O_2$	6.34

γ-Linolenic acid (C18:3c)	278	$C_{18}H_{30}O_2$	0.29
Linoleic acid (C18:2)	280	$C_{18}H_{32}O_2$	17.9
Oleic acid (C18:1c)	282	$C_{18}H_{34}O_2$	1.44
Vaccenic acid (C18:1)	282	$C_{18}H_{34}O_2$	55.9
Stearic acid (C18)	284	$C_{18}H_{36}O_2$	2.13
Palmitoleic acid (C16:1)	254	$C_{16}H_{30}O_2$	0.15
Palmitic acid (C16:0)	256	$C_{16}H_{32}O_2$	4.25
Myristic acid (C:14)	228	$C_{14}H_{28}O_2$	0.05

According to literature [23], the methyl esters comprised of more monounsaturated, less polyunsaturated and mild saturated fatty acids, have the best Cetane number and cold temperature performance (in terms of cloud and pour points). As can be seen from Table 3, the contribution of monounsaturated, polyunsaturated and saturated fatty acid in Eruca Sativa oil was 62.78, 24.81 and 11.89%, respectively; which remarkably follows the distribution suggested by literature [23]. Also, it has been declared that cetane number decreases slightly as the degree of unsaturation increases. The cetane number of fatty esters depends on chain length and degree of unsaturation [21]. However, only 10.74% of fatty acids in Eruca Sativa oil was from higher unsaturation degrees (polyunsaturation). On the other hand, as the chain length of fatty acids increases, pour point of methyl esters increases. In this case, the contribution of long, average, and short chain fatty acid in Eruca Sativa oil was found to be 10.74, 84.29 and 4.45%, respectively. It is worth quoting that the compressibility decreases with increasing length of chain and increased unsaturation degree of the methyl ester [22]. However, the higher compressibility of methyl esters can lead to advanced injection timing. This is in line with the well documented observation that biodiesel fuels yield higher NO_x emissions. Therefore, there should be a tradeoff between fatty acid composition when attempting to enhance methyl esters quality factors.

Table 3. Saturated, unsaturated, monounsaturated and polyunsaturated as well as long, average, and short chain fatty acids distribution in Eruca Sativa oil

Category	Type of fatty acid	Value (%)
Saturation	Saturated fatty acid	11.89
	Unsaturated fatty acid	88.11
Degree of unsaturation	Monounsaturated fatty acid	62.78
	Polyunsaturated fatty acid	24.81
Chain length	Long chain fatty acid	10.74
	Average chain fatty acid	84.29
	Short chain fatty acid	4.45

3.3. Methyl Ester Characteristics

The produced Eruca Sativa methyl ester was analyzed to determine and evaluate its characteristics i.e. biodiesel conversion, dynamic viscosity, density, cetane number, water content, flashpoint, pour point, and acid value. The characteristics of the produced biodiesel from Eruca sativa were also compared with palm and Jatropha methyl esters and conventional petrodiesel and also, the quality of the produced methyl esters was conformed and coped with ASTM and EN international standards as declared in Table 4. According to Table 4, the FAME contents in final produced biodiesel was found to be 95.61% which did not pass the EN 14103 test method (at least 96.5% fatty acid methyl esters). This means that 95.61% of the final product is fatty acid methyl esters and the rest comprises of monoacylglycerol, diacylglycerol and triacylglycerol as the intermediate results of transesterification reaction. However, minor constituents like monoacylglycerol and diacylglycerol in biodiesel contribute essentially to the lubricity of low level blends of biodiesel (B1-2) with low lubricity petrodiesel [21].

Moreover, the density of the biodiesel was 882 kg/m^3 which lies in the range of EN ISO 3675 standard (860-900 kg/m3). Taking into consideration the fact that methyl ester fatty acids have often higher densities than pure petroleum diesel (839 kg/cm^3), the density of methyl ester blended with diesel is higher than pure diesel fuel, serving as the higher density of the final blend. Higher density leads to higher injected fuel mass to the combustion chamber, higher heat and power [24]. From another stand of point, due to the higher densities of biodiesel compared to pure diesel, it can be considered as 'chemically advanced' concerning injection timing; so that for the same engine, it will take a shorter time for biodiesel compared to petroleum diesel to run from the injection pump to the injector which consequently makes up the lower heating value of biodiesel [25]. Accordingly, it is more preferable to have methyl esters with higher densities and necessarily lying within the range of international standards. Interestingly, the density of the Eruca Sativa biodiesel complied with the standard EN ISO 3675 and also was the highest as compared with palm and Jatropha methyl esters.

The viscosity of the Eruca Sativa biodiesel was obtained as 4.8135 mm^2/s. Generally, unsaturated chains of fatty acids and degree of unsaturation contribute to a reduction in viscosity. Higher viscosities remarkably reduce the flow of fuel; the ASTM specifications recommend a limit for viscosities, ranged from 1.9 to 6.0 mm^2 s^{-1}. The viscosity of the produced biodiesel lied within the limits of ASTM (D445) and interestingly was satisfactory as compared with the viscosity of biodiesel produced from other feedstocks (Palm and Jatropha).

The flashpoint stands for the lowest temperature at the standard atmospheric pressure (101.3 kPa), at which the vapors of the fuel above liquid phase will potentially ignite, given a spark or flame. According to the ASTM specification (D93), biodiesel must have a minimum flashpoint of 130°C. The flashpoint of Eruca Sativa biodiesel was obtained as 164^{o}C which conformed to the ASTM limit. Taken as a whole, due to the fact that in Compression Ignition (CI) engines there is no spark and the fuel blend ignites with only compression, the higher flashpoints of such fuels can be more preferable and even safe concerning storage safety. Flashpoint will vary due to different feedstocks and other factors. Generally, the presence of unseparated alcohols (methanol and ethanol) in the final product as a result of transesterification process influences the flashpoint.

According to Table 4, the biodiesel flashpoint is considerably higher than pure petrodiesel (90 vs 164^{o}C), leading to increase final fuel flashpoint as blended with biodiesel which makes it a much safer fuel than petroleum diesel.

Furthermore, water content of Eruca Sativa biodiesel was found to be 9.17 mg/kg. The presence of water in biodiesel, as an undesirable point in product quality can adversely affect the combustion performance as well as bring about tank corrosion, hydrolysis of esters incomplete combustion through the engine and other deteriorating effects. Hence, the maximum limit of water contents in biodiesel has been ratified by EN standard at 500 mg/kg. The water contents of Eruca Sativa biodiesel fitted within EN ISO 12937 standard, though was the highest value among other feedstocks i.e. palm and Jatropha.

The cetane number of Eruca Sativa biodiesel was obtained to be 54 and conformed to ASTM D613 specifications which suggests a minimum cetane number of 47. Also, the Cetane number of biodiesel produced from Eruca Sativa oil was the highest among other biodiesel feedstocks (Palm and Jatropha). Cetane number, as a prevalent indicator of diesel fuels' quality, is an inverse function of fuel ignition delay and the time period between the start of the fuel injection and the start of the fuel ignition as sprayed into the hot compressed air. Hence, the higher cetane number will lead to a shorter ignition delay period, less unburned fuel in the cylinder, less knock caused by delayed ignition as well as smooth and quiet fuel ignition within engines with less depreciation, wear and tear on the starter and batteries. Noteworthily, regular diesel fuel has a cetane number of 48 and when it blends with Eruca Sativa methyl esters (with cetane number of 54) translates to higher cetane number of final product compared to pure regular diesel; introducing Eruca Sativa biodiesel as a prominent cetane improver. For instance, a B20 biodiesel and diesel fuel blend will have cetane number of 50 rather than 48 in pure regular diesel. Overall, biodiesel cetane number mainly depends on the structure and distribution of fatty acid methyl esters. According to literature [26], it has been declared that the longer fatty acid chains and the lower unsaturation degree, lead to the higher Cetane Number.

Furthermore, the acid value of Eruca Sativa biodiesel was 0.27 mg KOH/g which is higher than petrodiesel acid value (0.17 mg KOH/g) but still meets the maximum limit of 0.8 mg KOH/g specified by ASTM D664 standard. It is worth mentioning that the acid value of Eruca Sativa biodiesel was moderate as compared with Jatropha and Palm methyl esters. The acid number is aimed to quantify the amount of acid values in the biodiesel and can be specified as the quantity of base (potassium hydroxide) that is needed to neutralize the acidic constituents in 1 g of sample. It has been reported that the higher the acid value, higher the formation of acidic products by oxidation [27]. Acid value is a measure of auto-oxidation, storage instability or metal contamination. Accordingly, it is more desirable to have methyl esters with lower acid values which is more stable and safe in terms of storage.

The pour point of -7 ^{o}C was obtained for Eruca Sativa biodiesel which exceeds the maximum limit of ASTM D97 standard (-10 ^{o}C). The pour point of a liquid fuel is the temperature at which the liquid loses its flow characteristics and ceases to pour. The pour point is an important factor which affects engine performance in low temperatures especially in cold weathers and regions. At this temperature the fuel is essentially unpumpable. At temperatures below pour point, the fuel crystals are too large to pass through the fuel filter, so they stick to the surface of the filter and injectors. If the fuel temperature keeps dropping, finally enough crystals will form to completely block the filter surface, leading to lack of enough fuel flow thereby choking the engine.

As a final point, most of the properties of Eruca Sativa methyl ester in comparison with that of other esters as well as ASTM and EN standards were quite comparable and potentially reasonable. However, further surveys should be carried out to enhance Eruca Sativa biodiesel conversion rate and minimize production costs which are the major problems in the case of biodiesel industry. It is suggested to investigate the possibility of Eruca Sativa methyl ester blending with methyl or ethyl esters produced from other feedstocks aimed at enhancing its performance and physicochemical characteristics e.g. cetane number, pour point and Sulphur contents.

4. Conclusion

In this study, the potential of Eruca sativa plant as an industrial and least-desirable edible source for biodiesel production was investigated, as well as the physicochemical characteristics of the oil and the produced methyl ester were compared with that other feedstocks. The biodiesel production was carried out through transesterification procedure by means of methanol as alcohol and potassium hydroxide (1%wt) as catalyzer in the presence of ultrasound power. According to fatty acid profile of Eruca Sativa oil obtained from GC analysis, about 88% of fatty acids within Eruca Sativa oil was unsaturated fatty acids and the highest proportion of fatty acids (55.91%) was pertained to Vaccenic acid (C18:1). Overall, the physicochemical characteristics of Eruca Sativa oil were found to be rational and potentially suitable for biodiesel production.

The quality of the produced fatty acid methyl ester was also conformed to ASTM and EN standards and compared with biodiesel obtained from other feedstocks. The characteristics of Eruca Sativa methyl ester i.e. FAME conversion, dynamic viscosity, density, cetane number, water content, flashpoint, pour point, and acid value were assessed and seemed to be rational and comparable with other feedstocks. Taken as a whole, most of the properties of Eruca Sativa methyl ester were in accordance with ASTM and EN standards specifications but still further studies should be performed in order to enhance production yield and improve characteristics of Eruca Sativa methyl ester. Higher cetane number, higher density, higher flashpoint and lower acid value can be expressed as strengths of Eruca Sativa methyl ester. On the other hand, higher pour point (-7 ^{o}C) was the weaknesses of Eruca Sativa methyl ester.

Finally, Eruca Sativa methyl ester can be considered as a potentially reasonable feedstock for biodiesel production according to its promising and comparable characteristics. However, further studies should be performed to enhance Eruca Sativa biodiesel conversion rate and minimize production costs which are the major problems in the case of biodiesel industry. Also, it is suggested to assess the prospects of Eruca Sativa methyl ester blending with methyl or ethyl esters produced from various feedstocks aimed at enhancing its yield and physicochemical features e.g. cetane number, pour point and Sulphur contents.

Table 4. Properties of produced biodiesel from *Eruca Sativa* oil

Parameter	Unit	Test Method	Limit		Eruca Sativa	Jatropha	Palm	Petro-diesel
			Min	Max				
FAME	%	EN 14103	96.5	-	95.61	93.96	98.13	-
Density at 15 °C	Kg/m^3	EN ISO 3675	860	900	882	862.3	866.4	839
Flashpoint	^oC	ASTM D93	130		164	178	171	90
Viscosity at 40 $^\circ$C	mm^2/s	ASTM D 445	1.9	6.0	4.85	4.34	6.41	2.6
Water content	mg/kg	EN ISO 12937	-	500	9.17	4.231	5.1	-
Cetane number	-	ASTM D613	47	-	54	-	-	48
Acid value	Mg KOH/g	ASTM D 664	-	0.8	0.27	0.15	0.46	0.17
Pour point	^oC	ASTM D97	-15	-10	-13	-	-	-

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