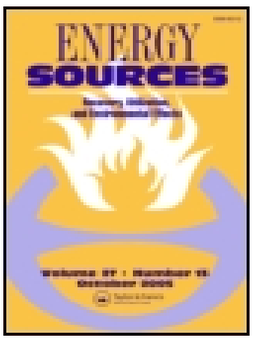

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Production and characterization of biodiesel from Jatropha *(Jatropha curcas)* seed oil available in Bangladesh

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ABSTRACT

In this study, biodiesel was produced from Jatropha (*Jatropha curcas)* seed oil available in Bangladesh. The percentage of the oil extracted from the seed using a mechanical expeller was found at 24.87%. As the free fatty acid content of crude Jatrpha oil was higher, acid-catalyzed esterification and base-catalyzed transesterification were carried out to produce biodiesel. The optimum condition for esterification was found as follows: addition of 90% methanol and 2.25% H_2SO_4 (both are based on the wt.% of oil), 60 °C temperature and 90-minute reaction time and that for the transesterification was found as follows: addition of 50% methanol and 0.8% NaOH (both are based on the wt. of oil), 60 °C temperature and 90-minute reaction time. The yield of biodiesel was found 95.09% at optimum condition. The fatty acid content in the produced biodiesel includes oleic acid (45.09%), linoleic acid (25.21%), palmitic acid (13.85%), and methyl tricosanoate (10.3%) as a major component. Viscosity, density, pour point, flash point, acid value, and calorific value of the produced biodiesel were found 5.18 cSt, 0.87 gm/cc, −10.01 °C, 96.6 °C, 0.49 mg KOH/g of oil, and 35.84 MJ/Kg, respectively. Six blends of biodiesel and commercial diesel were prepared and their performances were measured. The produced biodiesel can potentially be used in blending with commercial diesel and contribute to the fuel economy of Bangladesh.

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Biodiesel; transesterification; Jatropha seed oil; parametric study; engine performance

Introduction

Our ever-increasing energy demand is currently met by fossil fuels, which are nonrenewable and supposed to be finished out shortly (Palash et al. 2013). Besides, the burning of fossil fuels emits enormous toxic gases which are responsible for current global warming (Bach 1981). As a result, searching for an eco-friendly renewable alternative fuel has become a major concern for researchers around the world. Biodiesel, chemically known as fatty acid methyl ester (FAME) and a modified form of vegetable oil, is one of the significant alternatives of petroleum-based fossil fuels (Bhattarai et al. 2011)(Atabani et al. 2012).

The use of vegetable oil or biodiesel in diesel engines is not a new concept. Even the inventor of diesel engines, Rudolf Diesel, first used peanut oil as the fuel to run his engine and presented this demonstration at the 1900 World Exhibition in Paris (Agarwal and Das 2014). In the recent years, however, biodiesel production from vegetable oils is one of the notable research areas, especially in countries where biomass and natural resources are widely available. Biodiesel has several benefits over commercial diesel. It is renewable, free of Sulfur and other harmful aromatic compounds, biodegradable, and provides excellent lubricity in the engine (Keera, El Sabagh, and Taman 2018). Burning of biodiesel is considered as zero carbon emission since the CO_2 released during the combustion of

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biodiesel can be equally captured by the next generation crops for the photosynthesis process in their body (Hanaki and Portugal-Pereira 2018). Moreover, due to the presence of a trace amount of Sulfur and Nitrogen, a lower amount of SO_x and NO_x emission occurs in biodiesel compared to conventional diesel. In addition, due to the presence of oxygen in esters, complete combustion occurs in biodiesel compared to conventional diesel (Agarwal and Das 2014).

As Bangladesh is an agro-based country and a large variety of biomass and natural resources are available here, biofuel (biodiesel, bio-oil, bioethanol, and biogas) production is a promising option to face the future energy crisis for this country. Different countries depend on various types of feedstocks for biodiesel production, e.g. the USA on soybean oil, Europe on rapeseed & sunflower oil, Malaysia & Indonesia on palm oil, and the Philippines on coconut oil (Morshed et al. 2011). Since most of the vegetable oils that are currently used for the edible purpose, the exploitation of these edible sources as biodiesel feedstock will create an imbalance between food and fuel. Hence, nonedible sources of feedstocks are currently studied and used for the commercial production of biodiesel.

Although different non-edible seeds are widely available in Bangladesh, only a few studies on some feedstocks, e.g. castor oil (Deb et al. 2017), rubber seed oil (Morshed et al. 2011), Karanja oil (Rahman et al. 2011), cottonseed oil (Nabi et al. 2009), and sal seed oil (Hasan et al. 2020) were carried out. However, no in-depth study on biodiesel production from *Jatropha curcas* available in Bangladesh was found, although it is one of the well-studied and most promising biodiesel feedstocks in the world. Characterization (de Oliveira et al. 2009), optimization of parameters (Johanes and Hirata 2008), engine performance and emission characteristics (Mo et al. 2013), and different heterogeneous catalysts use for transesterification (Endalew, Kiros, and Zanzi 2011; Taufiq-yap et al. 2010) process for *Jatropha curcas* oil methyl ester (JCOME) production were reported in various parts of the world. Application of artificial neural network to measure engine performance, emission, and combustion of JCOME has also been reported (Silitonga et al. 2015). Furthermore, a good number of review articles are available on JCOME (Silitonga et al. 2013)(Silitonga et al. 2011). This study focuses on the biodiesel production from the native *Jatropha curcas* oil (JCO) of Bangladesh as the fatty acid composition and other properties of oil varies depending on geographical position and climatic condition (Lajara, Diaz, and Quidiello 1990).

Jatropha curcas, also known as Jatropha and Physic nut, is a non-food, deciduous short tree or large shrub that belongs to the family Euphorbiaceae. Usually, it is 3–5 meters tall, but in proper conditions, it can be raised to a height of 8–10 meters (Kumar and Sharma 2008). The Jatropha seed is oval in shape and the average diameter of the seed was 10–17 mm with an average weight of 0.76 g per seed. Kumar et al. (Kumar and Sharma 2008) reported that a maximum of 2500 Jatropha trees can be planted in each hectare area in Bangladesh with 2-meter gap between each plant. In Bangladesh, the climatic condition is suitable for the Jatropha plant growth, although it has no commercial application in this country (Nabi, Akhter, and Islam 2007). This plant is mostly used as a fence in agricultural fields.

Vegetable oil can be converted to biodiesel in four different ways, e.g. dilution, pyrolysis, transesterification, and micro-emulsification (Gerpen and Knothe 2010). All of these techniques reduce the viscosity of vegetable oil which is a prerequisite for direct injection of oil into the engine. Here, the transesterification process with the optimization of process parameters was induced to convert JCO to JCOME. For an effective transesterification process, the presence of lower free fatty acid (FFA) in raw oil is an essential pre-requisite. Hence, in the case of oil containing higher FFA, acid-catalyzed esterification is carried out before performing the base-catalyzed transesterification process to yield biodiesel. This study also characterizes the produced JCOME to evaluate the properties of the produced biodiesel and to compare it with the internationally determined standard for biodiesel. Finally, the fuel consumption test of the produced JCOME and its blending (5%, 10%, 15%, 20%, 25%, and 30%) with commercial diesel has been studied.

Materials and methods

Seed collection and preparation

Naturally grown Jatropha plant is available almost everywhere in Bangladesh. Mature seed pods were collected from the road-side plants of Sreenagar, Munshiganj, Bangladesh. Collected seed pods were sun-dried for 2 days. Then the pods were dehulled manually to get the actual seeds. The collected Seeds were dried again to minimize the amount of moisture present in seeds. The seeds were then stored in a clean, dry, and well-ventilated place for oil extraction.

Oil extraction and characterization

Oil extraction can be performed through techniques, e.g. soxhlet extraction, ultrasonication, mechanical expeller, etc. Here, a screw-type mechanical expeller was employed to extract oil from seeds. The effect of temperature and extraction time was also analyzed to identify the optimum condition for oil extraction. The extracted oil was filtered to remove suspended impurities. Extracted oil percentage was calculated by dividing the weight of oil by the initial weight of the feed (Equation 1). Several physico-chemical parameters, e.g. acid value, free fatty acid content, and specific gravity were determined.

$$\text{Oil content}(\%) = \frac{amount\ of\ extracted\ oil(g)}{weight\ of\ seed\ taken(g)} \times 100\% \quad (1)$$

Esterification of oil

Higher acid value *i.e.* a higher percentage of Free Fatty Acid (FFA) is considered as the major drawback for biodiesel production from direct vegetable oil. Jatropha oil was found to have 18.4% FFA, which was unfavorable for direct base-catalyzed transesterification. Hence, an acid-catalyzed esterification process was carried out to reduce the acid value and FFA. The esterification process was performed in a round bottom flask with a condenser attached to the neck of the flask. Methanol was used as an esterifying agent, whereas H_2SO_4 was used as a catalyst. The effects of variation of acid value and free fatty acid content with a weight percentage of methanol and H_2SO_4, temperature, and reaction time were studied to find out the optimum condition. An amount of 90% (w/w of oil) methanol and 2.2% (w/w of oil) H_2SO_4 were mixed with the oil in the round bottom flask to carry out the esterification reaction. For maximum FFA reduction, the temperature was kept at 60 °C for 90 minutes with continuous stirring with a magnetic stirrer maintaining 400 rpm. After the esterification process, the mixture was allowed to settle in a separating funnel for 12 hours; two distinct layers were found which were then separated out. The bottom layer contained the esterified oil and was collected for the transesterification process.

Transesterification of oil

For biodiesel production, esterified oil was taken into a three-necked round bottom flask. Two of these necks were fitted with a condenser and a thermometer and the third one was for charging raw material. The whole arrangement was kept in an oil bath to maintain uniform heating. Optimization of biodiesel production was performed by considering the parametric effect of weight percentage of methanol and NaOH, temperature, and time on the yield of biodiesel. Finally, biodiesel was produced under optimum condition. For transesterification reaction, 50% (w/w of oil) methanol and 0.80% (w/w of oil) NaOH were mixed with esterified oil in the reactor at 60 °C. The reaction was performed for 90 minutes with continuous stirring at 400 rpm. By this reaction, all the esters present in the oil mixture converted into their methyl esters and glycerin. For the separation of biodiesel, the mixture was kept in a separatory funnel for 12 hours and then the upper layer, which is biodiesel, was collected. For purification of biodiesel, hot

water was sprayed over the biodiesel at 60 °C with stirring until neutral pH was obtained (Atabani and César 2014). Then the upper layer (biodiesel layer) was reseparated and dried using a rotary evaporator. Statistical analysis of the transesterification process was performed by IBM SPSS Statistics 20 (NY, USA). A one-way Analysis of Variance (ANOVA) was used to compare the means of the dependent variable (biodiesel yield) among different groups of independent variables (methanol concentration, NaOH concentration, time, and temperature).

Composition of the produced biodiesel

The functional groups present in biodiesel were detected by Fourier Transform Infrared Spectroscopy (FTIR) (Shimadzu, Japan). The wavelength of light used was in the range of 4600 cm^{-1}– 500 cm^{-1}. The resolution and the number of scans were 8 cm^{-1} and 32 times, respectively. The fatty acid composition of JCOME was determined with gas chromatography (GC). The separated gases in quartz column (30 m long and 0.25 mm inner diameter) were detected by a Flame Ionization Detector (Shimadzu, Japan). Inert nitrogen gas was passed to carry the sample and the flame used in the detector was produced by hydrogen and air.

Physico-chemical characteristics of produced biodiesel

Different physico-chemical properties of the produced biodiesel were determined using international standard methods. Viscosity, pour point, flash point, acid value, and e ash content were measured using ASTM-D 445–65, ASTM-D 97–57, ASTM-D 64–50, ASTM-D 974–02, and ASTM-D 975–80a methods, respectively. The density of the biodiesel was determined with a 25 mL pycnometer at 40 °C and the calorific value was measured with a bomb calorimeter following standard procedure. The Cetane number (CN) was determined by the empirical equation (Equation 2) based on fatty acid composition (Mishra, Anand, and Mehta 2016).

$$\mathrm{CN} = 63.41 - (0.0728 \times \mathrm{DU}) + (0.03495 \times \mathrm{SCSF}) - \left(3.26 \times 10^{-4} \times \mathrm{DU} \times \mathrm{SCSF}\right) \tag{2}$$

In this equation, the Cetane number depends on two quantities – Degree of Unsaturation (DU) and Straight Chain Saturation Factor (SCSF) which can be determined by Equations 3 and 4, consecutively.

$$\mathrm{DU} = (\mathrm{monounsaturated}C_n{:}\ 1, \mathrm{wt}\%) + 2 \times (\mathrm{polyunsaturated}C_n{:}\ 2, \mathrm{wt}\%) + 3 \times (\mathrm{polyunsaturated}C_n{:}\ 3, \mathrm{wt}\%) \tag{3}$$

$$\mathrm{SCSF} = \frac{1}{100} \sum (\mathrm{MW_i} \times \mathrm{wt}\%\ \mathrm{ofsaturated\ methylesters}) \tag{4}$$

Engine performance

The fuel consumption test was carried out in a four-stroke diesel engine to study the performance of the produced Jatropha oil biodiesel blended with commercial diesel. For the same amount of samples (45 mL), the total duration of running the engine was measured and compared. Firstly, the performance of pure commercial diesel was studied as the base case (JB-0) and then six mixtures (commercial diesel + JCOME)- JB-5, JB-10, JB-15, JB-20, JB-25, and JB-30 were tested. Here, JB-5, JB-10, JB-15, JB-20, JB-25, and JB-30, respectively, indicate the 5%, 10%, 15%, 20%, 25%, and 30% blending of Jatropha biodiesel with commercial diesel. The biodiesel was blended with commercial diesel in a reactor using a high speed rotating agitator.

Results and discussion

Effects of temperature and time on JCO extraction process

JCO was extracted from the Jatropha seed by a screw-type mechanical expeller. At optimum condition (60 °C temperature and 10 minutes of extraction time), the extracted oil percentage was found to be 24.87 wt.%. The effects of temperature and extraction time on oil percentage were studied to get the optimum condition. The effect of temperature was observed from 40 °C to 70 °C with a 10 °C interval shown in Figure 1(a). After 60 °C, no significant difference in oil yield percentage was observed in the graph. Therefore, the most suitable temperature for oil extraction was 60 °C. The amount of oil yield percentage was also varied with extraction time (Figure 1(b)) in the expeller. The oil was extracted for 6, 8, 10, and 12 minutes consecutively and it was found that the amount of oil yield after 10 minutes did not change. Hence, 10 minutes of extraction time was the most suitable time for the extraction of oil from Jatropha seed.

Physico-chemical characteristics of extracted raw oil

The physico-chemical properties of JCO were determined and listed in Table 1. The color of the oil was pale yellow. The acid value of the oil was found to be 36.20 mg KOH/g, which was unsuitable for direct conversion to biodiesel. The oil was in a liquid state at room temperature. The specific gravity of the oil was obtained 0.923, which is slightly higher with compare to some common biodiesel feedstocks, e.g., *Heveabrasiliensis* (0.91), *Pongamiapinnata* (0.913), Calophylluminophyllum (0.89), etc. (Atabani and de César 2014).

Effects of parameters on esterification process

As the acid value and the FFA content of the extracted oil were considerably higher, neutralization of the free fatty acid was performed with methanol using H_2SO_4 as a catalyst. However, optimization of the process parameters was required for the successful esterification process.

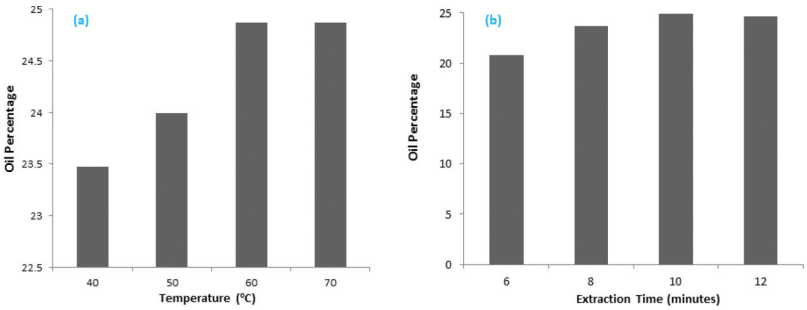

Figure 1. Dependance of oil percentage on (a) Temperature & (b) Extraction Time.

Table 1. Physico-chemical characteristics of Jatropha oil.

Sl no.	Physico-chemical parameters	Unit	Values
1	Acid value	mgKOH/g	36.20
2	Free fatty Acid	%	18.4
3	Physical state at 25 °C	-	Liquid state
4	Specific gravity	-	0.923
5	Color	-	Amber/pale yellow
6	Extracted Oil percentage	%	24.871

Effect of amount (wt.%) of methanol on FFA reduction from oil

In acid-catalyzed esterification, free fatty acids react with methanol to convert into its methyl ester. Therefore, the amount of methanol is an important parameter to control the process. The amount of methanol is inversely proportional to reaction completion time. Although the higher amount of methanol will reduce reaction time, it increases overall production cost. Hence, the effect of amount (wt%) of methanol addition required for the esterification process was studied keeping other parameters constant to determine the optimum condition. The temperature and the duration of the esterification process were kept fixed at 60 °C and 90 minutes.

The weight percentage of methanol required for the esterification process was studied by adding 30 wt.% to 90 wt.% methanol compared to the amount of oil. The relationship between the reduction of FFA content and the amount of methanol addition was shown in Figure 2(a). In this study, the addition of 90 wt.% of methanol showed the desired result; the FFA content in the oil reduced to 1.62%. For all other the amount of methanol below 90%, the FFA content was higher than 2%. Therefore, for the optimization of remaining parameters and final esterification, the addition of 90 wt. % methanol (compared to the amount of extracted oil amount) was used as the standard.

Effect of addition of H_2SO_4 (wt.%) on FFA reduction from oil

H_2SO_4, HCl, $Fe_2(SO_4)_3$, H_3PO_4, and different organic sulfonic acids have been reported to use as catalyst in transesterification reaction of biodiesel production (Silitonga et al. 2013). As sulfuric acid was used as a catalyst for the esterification process in this study, catalyst dosage was a key parameter for proper conversion. Seven catalyst dosages (1%, 1.25%, 1.50%, 1.75%, 2%, 2.25%, and 2.50%) were studied. All the dosages were based on the weight/weight of the oil. The effect of catalyst addition on the FFA reduction is depicted in Figure 2(b). Among the studied range, the addition of 2.25 wt.% acid minimized the free fatty acid content below 2% (which is desirable for the transesterification process). The addition of acid lower than 2.25 wt.% could not reduce the FFA content at the desired level. In contrast, the addition of acid higher than 2.25 wt.% did not have any effect on FFA reduction. It indicated that a further increase in catalyst dosage had no catalytic activity to transform the free acids to methyl ester.

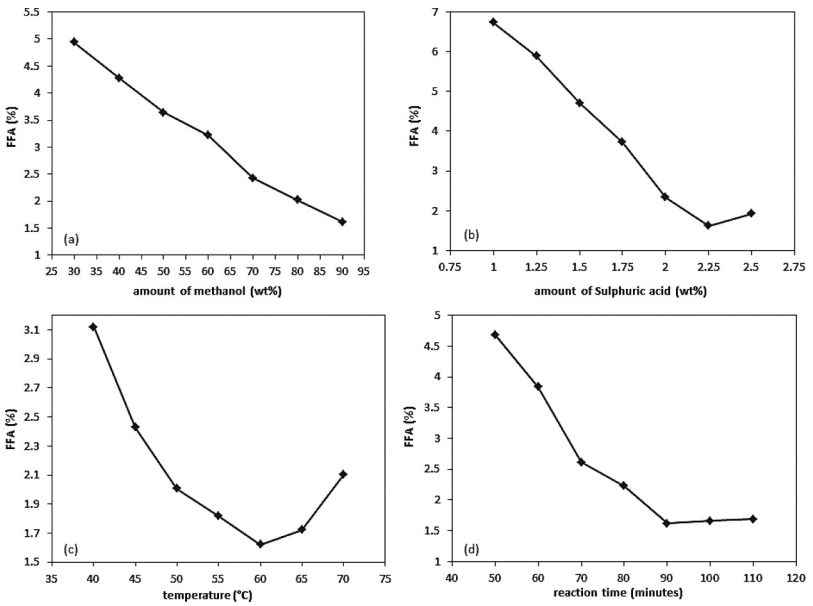

Figure 2. Effect on free fatty acid (FFA) content in extracted oil with the change of **(a)** amount of methanol addition, **(b)** amount of sulfuric acid addition, **(c)** temperature, and **(d)** reaction time.

Effect of temperature on FFA reduction from oil

The effect of temperature on FFA reduction was studied in the temperature range of 40 °C to 70 °C with 5 °C interval and the results are shown in Figure 2(c). With the increase of temperature, the FFA content reduced proportionally until 60 °C. For instance, at 40 °C and 60 °C, the FFA content reduced to 3.12 wt.% and 1.62 wt.%, respectively. However, with the increase of temperature after 60 °C, the FFA content reduced to 2.1 wt.% maintaining all the other conditions the same as in the 40 °C–60 °C. Therefore, the optimum temperature was set at 60 °C for the esterification of JCO, which is similar to the temperature identified by Dharma and his research group (Dharma et al. 2017).

Effect of reaction time on FFA reduction from oil

To observe the effect of reaction time, other parameters, e.g. methanol to oil ratio (by weight), catalyst concentration (by weight), and temperature were kept fixed at 90%, 2.25%, and 60 °C, respectively. The FFA content reduction experiments were carried out keeping the reaction time for 50, 60, 70, 80, 90, 100, and 110 mins and the findings are illustrated in Figure 2(d). For 50 mins reaction time, the FFA content was found 4.68% while after 90 mins reaction time, the FFA content reduced to 1.62%. For further increase in reaction period, the FFA content increased due to reversible reaction (Ijaz et al. 2016).

Effect of parameters on transesterification

Transesterification is a fundamental process for biodiesel production. In this process, the esterified oil is treated with methanol in the presence of a base catalyst to transfer the ester of oil into methyl ester. The reason for converting the esterified oil to methyl ester is that methyl esters have lower viscosity (near commercial diesel) than the vegetable oil itself. Optimization of the process parameters for transesterification is essential to get the desired yield. The effects of addition of methanol, NaOH, temperature, and reaction time were studied to identify the optimum conditions. One-way ANOVA analysis was performed for every parameter of transesterification reaction. Every parameter here showed a statistically significant difference with biodiesel yield, as the significance value (or p-value) was less than 0.001 for each case and thus rejecting the null hypothesis.

Effect of addition (wt.%) of methanol on biodiesel yield

The amount of methanol addition in the reaction is a significant parameter for biodiesel production via transesterification. As stated earlier, for esterification process, the addition of a lesser amount of methanol will require higher reaction time whereas the addition of f a higher amount of methanol will increase the cost of production. In this experiment, seven different batches were used (Figure 3(a)) where the methanol to oil ratio was maintained in the following ratio: 35 wt.%, 40 wt.%, 45 wt.%, 50 wt.%, 55 wt.%, 60 wt.%, and 65 wt.%. Among the studied samples, methanol to oil ratio of 50 wt.% showed a maximum yield of 95.09%. Below and above this ratio, the relatively lower conversion was observed. Addition of less than 50 wt.% methanol, the conversion hindered whereas the addition of more than 50 wt.% methanol causes interference in the separation of methyl ester and glycerol for increased solubility of glycerin (Musa 2016).

Effect of addition of NaOH on biodiesel yield

Sodium hydroxide (NaOH) was used as a catalyst for the transesterification process. Various dosages of catalyst (w/w of oil) were prepared, added in the reaction and the corresponding biodiesel yield was recorded. The yield of biodiesel is presented in Figure 3(b). The studied dosages were 0.50%, 0.60%, 0.70%, 0.80%, 0.90%, 1.0%, and 1.1 wt.%. For the dosages from 0.5 to 0.7 wt.%, the methyl ester (biodiesel) yield was very low. At 0.80 wt.% catalyst addition, the biodiesel yield was the highest. Further increase in catalyst concentration reduced the yield significantly as a higher amount of NaOH promoted the formation of emulsion that increased viscosity and led to the formation of gel (Sahoo and Das 2009).

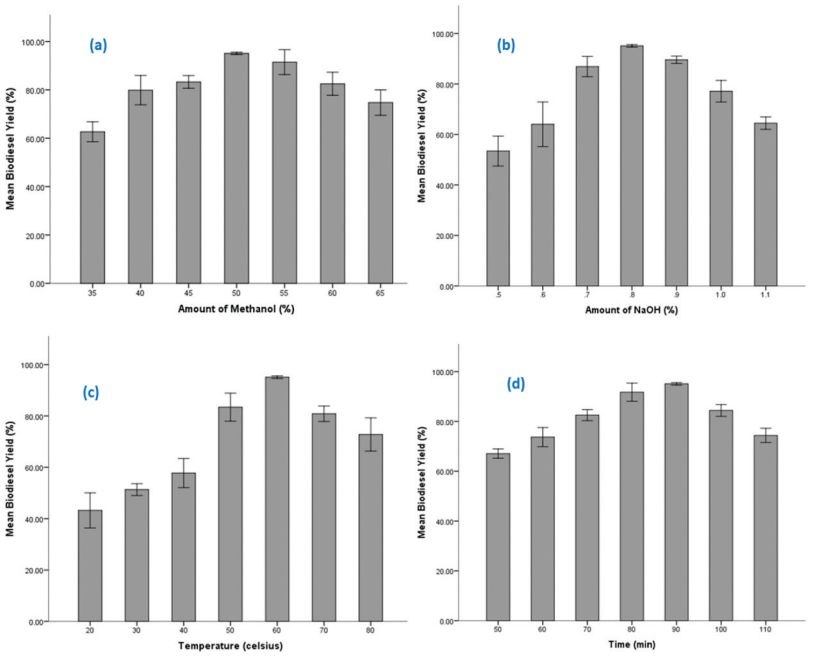

Figure 3. Variation of biodiesel yield with the change of **(a)** amount of methanol addition, **(b)** amount of NaOH addition, **(c)** temperature, and **(d)** reaction time during the transesterification process.

Effect of temperature on biodiesel yield

The yield of biodiesel via transesterification process from JCO was studied at 20 °C, 30 °C, 40 °C, 50 °C, 60 °C, 70 °C, and 80 °C and the results are presented in Figure 3(c). Initially, the yield increased with the increase of temperature, however, above 60 °C, the yield started to decrease. Therefore, the optimum temperature was found at 60 °C. It is presumed that above 60 °C, there might increase the evaporation of methanol which led to the reduction of biodiesel yield.

Effect of reaction time on biodiesel yield

For proper conversion of oil into biodiesel, sufficient time should be assigned to ensure the effective interaction between reactant molecules, but not the product molecules. To find out the optimum reaction time, seven reaction time points (50, 60, 70, 80, 90, 100, and 110 mins) were tested and the findings are reported in Figure 3(d). It is obvious from Figure 3(d) that the most suitable reaction period was 90 mins. The product yield at this point was 95.09%. Further increase in reaction time reduced the yield as it promoted the reverse reaction.

Fatty acid composition in biodiesel

The fatty acid composition of JCOME was determined by gas chromatography and the corresponding chromatogram is presented in Figure 4. The detected fatty acids of the JCOME are listed in Table 2 and compared with fatty acid compositions of methyl esters of some commonly available methyl esters in Bangladesh, e.g. castor oil methyl ester (COME), rubber seed oil methyl ester (RSOME), karanja seed oil methyl ester (KSOME), and cotton seed oil methyl ester (CSOME) (Mishra, Anand, and Mehta 2016)(Keera, El Sabagh, and Taman 2018).

A total of eleven fatty acids were detected in JCOME, among which oleic acid (45.09%) and linoleic acid (25.21%) were the major constituents. Among other fatty acids, Palmitic acid (13.85%), and methyl tricosanoate (10.33%) were significant in amounts, while each of the other seven fatty acids was

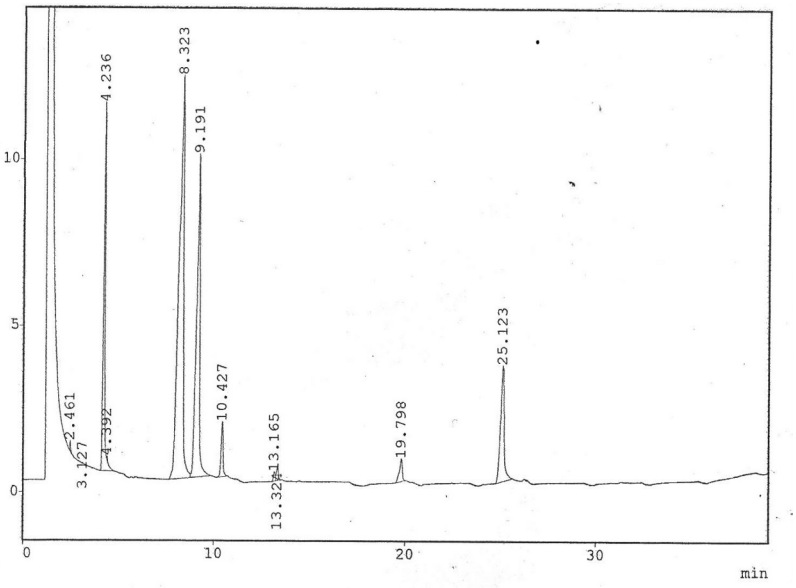

Figure 4. Gas chromatogram (GC) of fatty acid composition of JCOME.

Table 2. Fatty acid composition of JCOME and its comparison with the fatty acid content in the other available biodiesels in Bangladesh.

Fatty acid	Formula	JCOME	COME (Keera, El Sabagh, and Taman 2018)	RSOME (Mishra, Anand, and Mehta 2016)	KSOME (Mishra, Anand, and Mehta 2016)	CSOME (Mishra, Anand, and Mehta 2016)
Myristic (14:0)	$C_{14}H_{28}O_2$	0.15	-	0.51	-	0.72
Myrisloleic (14:1)	$C_{14}H_{26}O_2$	0.01	-	-	-	-
Palmitic (16:0)	$C_{16}H_{32}O_2$	13.85	0.92	9.39	10.89	25.93
Palmitoleic (16:1)	$C_{16}H_{30}O_2$	0.05	-	-	-	0.36
Stearic (18:0)	$C_{18}H_{36}O_2$	-	0.16	9.41	7.89	1.74
Ricinoleic (18:1-OH)	$C_{18}H_{34}O_3$	-	89.27	-	-	-
Oleic (18:1)	$C_{18}H_{34}O_2$	45.09	3.53	24.22	53.56	15.98
Linoleic (18:2)	$C_{18}H_{32}O_2$	25.21	4.21	38.12	21.34	55.12
Linolenic (18:3)	$C_{18}H_{30}O_2$	2.60	0.91	17.54	2.09	0.16
Arachidic (20:0)	$C_{20}H_{40}O_2$	0.45	-	0.28	1.82	0.22
Eicosenoic (20:1)	$C_{20}H_{38}O_2$	0.63	-	0.12	1.15	-
Docosanoic (22:0)	$C_{22}H_{44}O_2$	1.60	-	0.08	4.11	0.11
Methyl tricosanoate (24:0)	$C_{24}H_{48}O_2$	10.33	-	-	1.33	-
Total Saturated Fatty Acid	-	26.38	1.08	19.67	26.04	28.72
Total Unsaturated Fatty Acid	-	73.59	97.92	80.00	78.14	71.62

below 3%. An almost similar composition was reported by Rahman et al. (Rahman et al. 2014), who investigated JCOME in Malaysia. The ratio of unsaturation and saturation was 2.79, which firmly indicates the dominancy of unsaturation in JCOME. The degree of unsaturation of JCOME, determined by Equation 3, was found 104.

Biodiesel quality is largely influenced by the type of fatty acids present along with their corresponding percentage. Heating of unsaturated fatty acid results in the polymerization of glycerides. As JCOME contains a high amount of unsaturated fatty acids, combustion can cause the formation of unnecessary products in the engine and cause deterioration of the lubricating system (Mittelbach

1996). Moreover, the presence of a higher percentage of polyunsaturated fatty acids in the biodiesel sample reduces oxidative stability significantly as polyunsaturated fatty acids are more susceptible to autoxidation (Knothe 2005). JCOME contained two polyunsaturated fatty acids – linoleic acid (18:2) and linolenic acid (18:3) with 27.81% in total which is lower than RSOME (55.66%) and CSOME (55.28%), but higher than COME (5.12%) and KSOME (23.43%).

Cold filter plugging point (CFPP), a measure of the low-temperature flow property of biodiesel, greatly depends on its long-chain saturated fatty acids. Ignoring the effect of unsaturation completely (Ramos et al. 2009), the CFPP of JCOME was calculated by Equation 6 which entirely depends on the long-chain saturation factor (LCSF). LCSF can be calculated from the relative percentage of palmitic acid (C:16), stearic acid (C:18), arachidic acid (C:20), docosanoic acid (C:22), and methyl tricosanoate (C:24) which is reflected in Equation 5 (Ramos et al. 2009).

$$\mathrm{LCSF} = 0.1 \times \mathrm{C16(wt.\%)} + 0.5 \times \mathrm{C18(wt.\%)} + 1 \times \mathrm{C20(wt.\%)} + 1.5 \times \mathrm{C22(wt.\%)} + 2 \times \mathrm{C24(wt.\%)} \tag{5}$$

$$\mathrm{CFPP} = 3.1417 \times \mathrm{LCSF} - 16.477 \tag{6}$$

Long-chain saturation factor and cold filter plugging point were found 5.71 °C and 1.46 °C, respectively, which is suitable for engine application.

Infrared spectroscopy study of JCOME

Infrared spectroscopy (FTIR) of JCOME was performed to identify the presence of different functional groups in the biodiesel. The FTIR spectrum of the biodiesel is shown in Figure 5 and corresponding functional groups are listed in Table 3.

Among the detected peaks, the presence of fatty oil can be identified by the distinct peaks at 1739.8 cm^{-1}, 1196.87 cm^{-1}, and 1163.08 cm^{-1} which indicate the C = O and C-O stretching of the ester group in oil. The peak at 723.33 cm^{-1} especifically denotes the presence of cis-disubstituted alkene or compounds derived from them like unsaturated fatty acids in the oil (Ajala et al. 2016). The bands at 1435.04 cm^{-1} and 1361.74 cm^{-1} indicate the C-H bending from the – CH_2- and – CH_3 group present in the long aliphatic chain of fatty acids.

Physico-chemical properties of JCOME

The physico-chemical properties of JCOME were determined and compared with COME (Deb et al. 2017), RSOME (Morshed et al. 2011), KSOME (Nabi, Hoque, and Akhter 2009), and CSOME (Nabi, Rahman, and Akhter 2009) in Table 4. The values were also compared with the JCOME value obtained from the jatropha plant found in Malaysia (**Rahman etal.** 2014) and Indonesia **(Silitonga etal.** 2011**).** Flash point, pour point, and calorific value were found relatively higher in JCOME from Malaysia, whereas viscosity and cetane number were slightly lower.

The Acid Value, an indication of the presence of free fatty acid in fuel, of JCOME was found 0.487 mg KOH/g. This value is slightly lower than that of the maximum value (0.5 mg KOH/g) of the biodiesel standard suggested by ASTM. However, it is yet higher than that of commercial biodiesel (0.34 mg KOH/g). The higher acid value of a fuel can degrade the lubrication system and corrodes the fuel supply system (Atabani et al. 2013).

The Viscosity is a measurement of resistance of a fluid to flow and the quality of biodiesel largely depends on its viscosity. Higher viscosity leads to poor atomization of fuel during the injection. In this study, the kinematic viscosity at 40 °C of JCO was found 25 cSt which means this biodiesel is unfavorable for direct injection in the engine. But the JCOME had a kinematic viscosity of 5.18 cSt at the same temperature, which falls in the range of ASTM biodiesel standard (1.9–6 cSt). The density of JCOME was 0.8739 gm/cc which is slightly higher in comparison with commercial diesel. However,

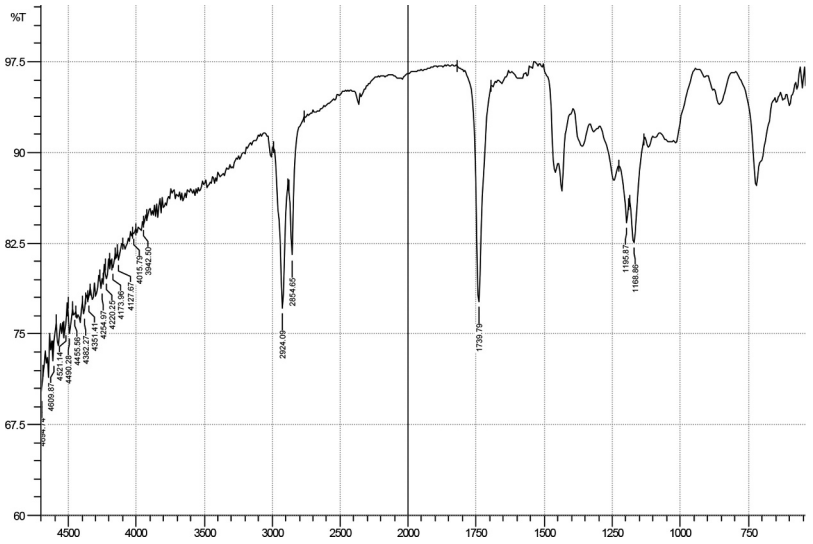

Figure 5. FTIR spectrogram of JCOME.

Table 3. Observed peaks in FTIR study of JCOME with corresponding functional groups.

Region of functional group	Wave number (cm^{-1})	Assigned functional group	Class of compounds
Hydrogen stretching	2924.09 2854.65	Stretching of aliphatic CH_2 group	Alkane
Double bond stretching	1739.79	C = O stretching of ester carbonyl of triglyceride	Aldehyde, ketone, carboxylic acid, α, β-unsaturated ester
Other bond deformation and bending	1435.04 1361.74	Bending of aliphatic CH_2 and CH_3	Alkane
Finger print region	1196.87 1163.08	Stretching of C-O group	Alcohols, esters
	723.33	Out-of-plane vibration of cis-disubstituted olefins	Alkene

it remains within the prescribed range of ASTM biodiesel standard (0.86–0.90 gm/cc). The effect of higher density, in terms of engine performance, is not as significant as viscosity but the higher density certainly increases fuel consumption and NO_x emission (Salaheldeen et al. 2015).

Pour point, one of the primary parameters helps to understand fuel behavior at low temperatures, and this is closely related to cloud point. Cloud point is the temperature at which the first lump of crystal appears in fuel during the cooling process, whereas, pour point is the temperature where crystals are enough to form a gel and the fuel loses its fluidity below this temperature. Fuels that have lower pour points are more suitable for application in cold regions. Usually, biodiesels show a higher pour point which limits its utilization in low-temperature regions. However, the pour point of JCOME was found relatively lower (−10 °C) compared to other biodiesels, e.g. Calophylluminophyllum (4.3 °C), Heveabrasiliensis (−8 °C), and Madhucaindica (6 °C). However, it is still higher than that of commercial diesel (−2 °C).

The flash point is the ignition temperature of the fuel. Fuel with high volatility has a lower flash point. Biodiesels usually have higher flash points compared to petroleum-based fuel. That is why biodiesels are more advantageous in terms of safety in handling and storage. Flashpoint of JCOME was relatively lower (96.6 °C) and the point was slightly lower than the minimum value of ASTM standard (100 °C). But, still, it was higher than the flash point of commercial diesel (70 °C).

Table 4. Physico-chemical characteristics of JCOME and compared with other available biodiesel in Bangladesh.

Sl no.	Properties	Unit	**Biodiesel standard** (Banik et al. 2018)	**JCOME**	**JCOME (Malaysia)** (Rahman et al. 2014)	JCOME (Indonesia) (Silitonga et al. 2011)	**COME** (Deb et al. 2017)	**RSOME** (Morshed et al. 2011)	**KSOME** (Nabi, Hoque, and Akhter 2009)	**CSOME** (Nabi, Rahman, and Akhter 2009)	**Commercial diesel** (Banik et al. 2018)
1	Viscosity at 40 °C	cSt	1.9–6	5.18	4.73	4.84	11.26	4.5	4.85	6	6.06
2	Density at 40 °C	gm/cc	0.86–0.90	0.87	0.87	0.88	0.9	0.85	0.89	0.85	0.85
3	Pour point	°C	−15 to 16	−10.01	3	3	−2	−5	-	−25	−2
4	Flash point	°C	100 to 170	96.60	184.5	191	178	120	180	-	70
5	Acid value	mg KOH/g	0.5 (max)	0.49	-	0.24	-	0.12	0.42	-	0.34
6	Calorific value	MJ/Kg	40.2	35.84	39.82	38.5	36.25	32.6	-	41.68	44.5
7	Cetane Number	-	48–60	55.93	51	51	57.3	51	58	52	51
8	Sulfide ash content	%	02	2.66	-	-	-	-	-	-	3.5

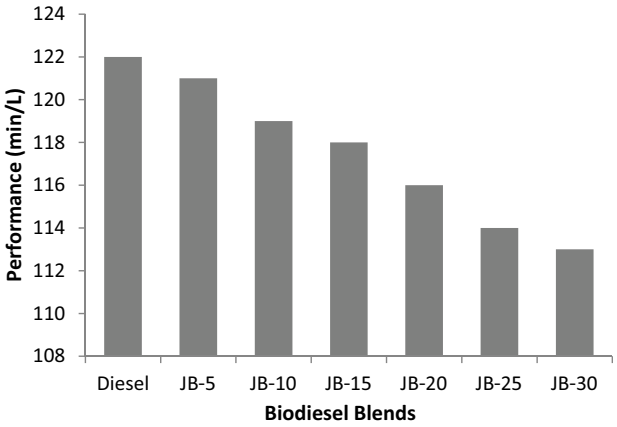

Figure 6. Engine performance (min/L) of commercial diesel and different biodiesel blends.

Cetane Number (CN) is a reverse quantity of ignition delay, i.e. higher CN indicates a short time of ignition after injection into the combustion chamber. Low CN of biodiesel negatively affects the combustion process, e.g. knocking, higher hydrocarbon, particulate matter emission and engine deposits (Atabani et al. 2013). CN of JCOME was found 55.93 which is in the range of biodiesel standard and higher than that of commercial diesel (51). Among all the methyl esters, KSOME had the highest CN (58) and RSOME had the lowest value (51).

Calorific value is the fundamental property of any fuel that measures the energy obtained during combustion of per unit mass of fuel. The calorific value of JCOME was obtained 35.84 MJ/Kg. It was moderately lower than the calorific value of commercial diesel (44.5 MJ/Kg). Higher oxygen content of biodiesels is the fundamental cause of lower calorific value. However, higher oxygen content essentially contributes to complete combustion in the engine (Graboski and McCormick 1998).

Engine performance

Produced biodiesel was tested in a diesel engine to study the engine performance. Biodiesel alone is not suitable for direct application in a diesel engine; rather it is used as a blend with conventional diesel. This is due to the fact that biodiesels have lower calorific value, high production cost, and high carbon deposition in the engine. Commercial diesel (collected from local fuel station) was blended with biodiesel with an aim to fulfil two specific benefits; improves the fuel property and reduces the environmental pollution.

The fuel consumption test was carried out for six blended mixture of JCOME with conventional diesel and compared the performances of these blended mixtures with conventional diesel alone. The six blended mixture contained 5%, 10%, 15%, 20%, 25%, and 30% JCOME and labeled as JB-5, JB-10, JB-15, JB-20, JB-25, and JB-30, respectively.

In the test, a fixed volume (45 mL) of each of all blended mixtures (biodiesel + conventional diesel as stated above) was introduced in the fuel tank and the engine was run at a speed of 2600 rpm. The running period for each mixture was recorded and compared with the running period of conventional diesel. The highest performance was obtained for (unblended) conventional diesel (122 min/L), whereas, among the blending mixtures, the VB-30 showed the lowest performance (113 min/L). The performance of other mixtures was in between these values and performance decreased with the increase of biodiesel percentage in the mixture. All the performance results are graphically presented in Figure 6.

Conclusion

This study reveals the characteristics of Biodiesel from *Jatropha curcas* seed found in Bangladesh. From the physico-chemical characteristics of the oil, it is evident that the jatropha biodiesel shows satisfactory physico-chemical, thermal and fuel characteristics. The higher portion of unsaturated fatty acids, e.g. oleic acid and linoleic acid are found as the major components of the biodiesel.

As the oil content of *Jatropha curcas* seed is relatively higher and the culture of the plant is feasible in Bangladesh, *Jatropha curcas* biodiesel can be a promising source for biofuel in Bangladesh to meet future energy crisis. An integrated approach, i.e., pyrolysis of the seed cake (the residue after oil extraction) along with biodiesel production from extracted oil can also be considered to maximize the utilization of the raw materials, which requires further investigation.

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