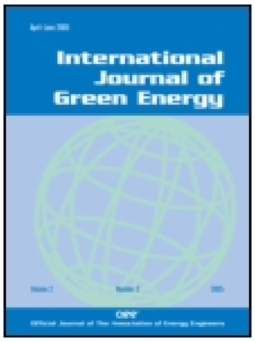

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# Rice bran: A prospective resource for biodiesel production in Bangladesh

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**ABSTRACT**
The increasing demand of renewable energy sources has pressed the need to search for biofuels. The world is not only thrusting for potential sources of biofuels but also surveilling not to hamper the food supply, particularly in the Third World countries, such as Bangladesh. Rice bran oil is a prominent source of biofuels. Rice, the main cereal in Bangladesh, is cultivated all the year round. Rice hull containing bran is mostly wasted and merely used as feedstock for cattle and for cooking purposes. This study considered rice bran as a prospective source of biodiesel in Bangladesh. The properties of oil collected from rice bran were investigated to ensure the production of biodiesel by transesterification. An economic analysis relative to Bangladesh was conducted, and the production rate of biodiesel under different percentage of catalyst was investigated.

**KEYWORDS**
Biodiesel; characterization; economic analysis; rice bran oil; transesterification process



## Introduction

With the escalating demand for energy in the modern world, the waning character of fossil fuels, and the impending adverse milieu, the renewable sources of energy are regaining their position to the summit. One of the popular renewable sources is biofuels, of which biodiesel is the most popular one. Biodiesel is a renewable, less polluting, and biodegradable liquid fuel that can be mixed with petroleum and diesel in any proportion or used directly in diesel engines with little modification (Thitsartarn and Kawi 2011). It is observed that several types of agricultural residues are available and ready to be utilized as fuels (Neethi Manickam and Subramanian 2006); for instance, arable crop residues such as straw or husks, animal manures and slurries (Biomass Energy Center), and coir pith (Neethi Manickam and Subramanian 2006).

Rice is the most important cereal cultivated in the world, which feeds more than half of the world's population, especially in east, south, and south-east Asia (Danielski et al. 2005; Venkata Subbaiah and Raja Gopal 2011). Rice bran is a non-edible portion of paddy as shown in Figure 1. Rice bran oil (RBO) is found to be the most nutritious oil because of its unique combination of naturally occurring biologically active antioxidant and favorable free fatty acid (FFA) composition (Ju and Zullaikah 2013). RBO is extracted from the germ and inner husk (called bran) of the paddy (Venkata Subbaiah and Raja Gopal 2011). It is very difficult to refine crude RBO because of its high FFA, acetone-insoluble content, and dark color (Ghosh 2007). However, because of the rapid hydrolysis reaction of its triglyceride into glycerol and FFAs immediately following the milling process caused by the presence of active lipase in the bran, only a little portion (<10%) of the total production of RBO is processed into edible oil (Ju and Vali 2005; Zullaikah et al. 2005). Because of the low value byproducts of rice milling with 15–20% lipid content, RBO is a potential candidate for biodiesel production (Ju and Zullaikah 2013). In the genesis of RBO production, it was mostly used as cooking oil because of its higher smoke point (about 257°C) than other vegetable oils, which prevents the oil from breaking down to form toxic substances (Jennings and Akoh 2009).

Transesterification is the most recognized way of producing biodiesel from crude oils of edible and non-edible origin (Ahmad et al. In press; Cao and Zhao 2012; Liu et al. 2012; Sadia et al. 2012). It is defined as a chemical reaction in which alcohol reacts with fat or oil in presence of a catalyst to form ester and glycerol (Aransiola et al. 2014; Atabani et al. 2013). There are mainly three types of transesterification processes based on the use of catalyst: these are base-catalyzed transesterification, acid-catalyzed transesterification, and lipase-catalyzed transesterification (Mathiyazhagan et al. 2011; Aransiola et al. 2014). All the three have their own benefits for biodiesel production from various resources depending on the FFA content, temperature, and reaction time (Ma and Hanna 1999; Watanabe et al. 2000; Lai et al. 2005; Einloft et al. 2007; Bhatti et al. 2008; Samios et al. 2009; Kafuku et al. 2010; Li, Zheng, and Yan 2010; Rizwanul Fattah et al. 2014). There are few other processes, viz. heterogeneously catalyzed processes and non-ionic base-catalyzed processes.

The history of using rice bran as biodiesel is not too old compared with the use of other vegetable oils. The use of rice bran as biodiesel mostly started after the middle-half of the millennium in the countries that produce plenty of rice and have resources to convert RBO into biodiesel (Yi-Hsu and Vali 2005). Such countries are the United States, China, India, Thailand, Brazil, Indonesia, Japan, and Vietnam. In Asia,

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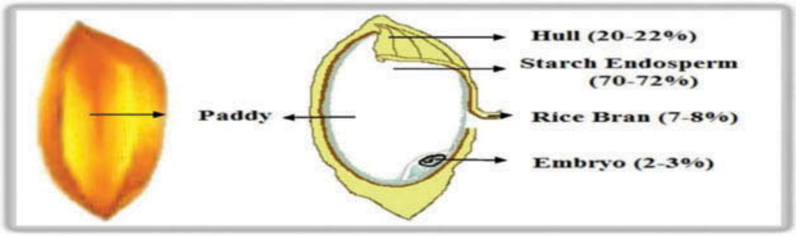


**Figure 1.** Structure of rice kernel.

India, China, Taiwan, and Indonesia are giving priority to the production of biodiesel from RBO.

However, till date there is no prior investigation or any research performed in Bangladesh to determine the prospect of producing biodiesel from RBO. This study mainly focuses on the prospect of producing biodiesel from RBO of Bangladesh origin, optimization of catalyst use for biodiesel production using transesterification process, investigation of the properties of produced biodiesel, and economic analysis compared with other biodiesels.

## Prospect of RBO for biodiesel production in BANGLADESH

The search for alternative sources of renewable energy has achieved a new dimension because of the limited source of petroleum. Different resources get prominent attraction to be selected as a renewable energy, such as solar energy, nuclear energy, tidal energy, hydro energy, wind energy, geothermal energy, and biodiesel. However, selection of such sources largely depends on the availability of their location. This study emphasizes biodiesel because of its superior benefits in response to installation and maintenance cost compared with other renewable sources.

According to the Energy and Mineral Resources Division (EMRD) of Bangladesh, three major resources (natural gas, coal, and petroleum) are used to meet the total energy crisis IEEJ 2012. Among these, natural gas plays the most vital role by ensuring 75% of the commercial energy (IEEJ, 2012). Nevertheless, most of this gas is used in the production of electricity, and for household and industrial purposes. A new sector is booming, which is compressed natural gas (CNG). Till March 2013, the total number of CNG converted vehicles was 209,054 (PetroBangla 2014), although the total number of registered petroleum vehicles was about 1,960,273 till October 2013 (BRTA 2013). Among them, total number of diesel vehicles were about 292,076 (BRTA 2013). This huge number of vehicles, as well as Bangladesh railways, consumed about 3.24 million metric ton (MMT) of high-speed diesel in the year 2011–2012 (IEEJ 2012). The current consumption of petroleum products in Bangladesh is 4.87 MMT/annum, whereas diesel consumption in Bangladesh is about 2.4 MT/annum, which is increasing at about 5% per annum whereas the annual growth rate is 4% (IEEJ 2012). The only natural resource to supply fuel (CNG) to these large number of vehicles in Bangladesh is natural gas, although the supply is hardly thirsting to meet the desired level of demand. On the other hand, the petroleum products are imported by using millions of dollars.

**Table 1.** Production of vegetable oil seed or source and estimation of vegetable oil production.

| Component | Cultivation area (acres) | Total production of oil seed or source (metric tons) | Projected estimation of oil (metric tons) |
|---|---|---|---|
| Jatropha | 1711.48[a] | 4.970 (projected by using: area 710 ha × 7 ton per hectre (Hazir and Amiruddin 2012) | 1.57 (based on 32%[C] oil content) |
| Sun Flower | 2344[b] | 747 | 209.16 (based on 28%[C] oil content) |
| Coconut | 6862[b] | 316,408 | 215,157.44 (based on 68%[C] oil content) |
| Soybean | 116,137[b] | 85,500 | 17,100 (based on 20%[C] oil content) |
| Rape and mustard | 416,945[b] | 138,226 | 41,467.8 (based on 30%[C] oil content) |
| Rice | 27,872,000[a] | 62,63,400 (projected production of rice bran and hull mixture; production in that year 31,317,000 × 20% oil content) | 1,252,680 (projected by using 6,263,400 × 20%[C] oil content) |

[a]Source: Global Market Study on Jatropha by WWF.
[b]Source: Bangladesh Bureau of Statistics (BBS).
[c]Standard value.

In Bangladesh, it can be undoubtedly said that the production of rice is peerless compared with that of other biodiesel raw materials such as jatropha, neem, sunflower, coconut, algae, cottonseed, soybean, and mustard. The main raw material for the production of biodiesel from RBO is rice bran, which is the non-edible portion of paddy. It can be easily collected from rice husks extracted from paddy. Different vegetable oil seeds or sources produced in the year 2008–2009 and the corresponding estimation of vegetable oil production are shown in Table 1.

If the estimated amount of RBO per year is converted into biodiesel, a huge amount of money can be saved for importing petroleum, and the unused rice bran can be used.

## Materials and method

### Materials

Rice bran oil was purchased from the local markets of Bangladesh. Raw material, such as methanol with 99.5% purity having a density of 0.792 kg/L, and NaOH pellets with 99.98% purity, were also purchased from respective chemical suppliers.

### Biodiesel production

The transesterification reaction is affected by several parameters such as the concentration of catalyst, oil to methanol ratio, reaction temperature, moisture, presence of FFAs, and agitation intensity (Vijaya Lakshmi et al. 2011). Selection of an appropriate and economical transesterification process is the first priority for biodiesel production. As the FFA content of collected RBO is less than 2%, the base-catalyzed transesterification process would be the right choice. Different studies have shown that the best reaction occurs at oil to methanol molar ratio of 1:5 to 1:7. A molar ratio greater than 1:5.25 is effective for better separation of ester and glycerol phases (Ma and Hanna 1999). The amount of catalyst can be varied from 0.5 to 2% by weight of oil. The average molecular weight of RBO is about 867.90 g/mol and 875 g/mol as reported by Li et al. (2011) and Lin et al. (2009), respectively. In this study, the molecular mass of RBO was taken as 867.90 g/mol. The molar mass of methanol was 32.04 g/mol. Thus, for producing biodiesel, 255.2 mL of methanol was mixed with 1 L of crude RBO (considering a 1:6 molar ratio of oil to alcohol). Because of availability and low cost, sodium and potassium hydroxides are currently used as industrial catalysts (Evangelista et al. 2012). For this study, about 18.26 g (for 2% catalyst) of NaOH as catalyst was needed, as the density of RBO is 0.913 g/mL. The reaction was carried out for 2 h, and the mixture was stirred at 600 rpm using an electric motor (rating 3.7 V and 1000 mAh). Afterwards, a separation time of 12 h was given to this mixture to separate glycerin from methyl ester or biodiesel. Methyl ester that was separated from glycerol was washed with distilled water to remove entrained impurities and glycerin. In this process, 50% (v/v) of distilled water at 60°C was sprayed over ester and shaken gently. The opaque lower layer containing water and impurities was taken out. Then methyl ester was distilled under vacuum at 65°C for 1 h using a rotary evaporator to remove water and methanol. Finally, methyl ester was dried using anhydrous $Na_2SO_4$ for 3 h and filtered using qualitative filter papers. The flow chart of biodiesel production from RBO is shown in Figure 2, and Figure 3 shows the pictorial view of different stages of RBO.

### Characterization of crude oil and biodiesel

Table 2 provides the list of equipment used to characterize crude oil and produced biodiesel.

## Results and discussion

### Physicochemical properties of crude oil

Among various vegetable oils, only RBO has the proper feasibility for the production of biodiesel with proper fuel properties. With the increasing productivity of rice, the prospect of rice bran for biodiesel production is now at the doorstep. As Bangladesh is an agricultural country and its main crop is rice, and as the production of rice is increasing annually because of modern technology, a huge amount of raw material can be obtained without any extra effort. If rice bran is selected as the main feedstock for biodiesel production in Bangladesh to reduce load on diesel, it will not only strengthen the economic backbone of Bangladesh but also help ensure the green environment. Bangladesh is not an oil producing country; a large percentage of budget is considered to import diesel, thus effecting the economic growth of the country. Rice bran can take that place and the economic condition can be improved with a free of extra cultivation effort to produce rice bran. The physicochemical properties of purchased crude oil are given in Table 3.

### Effect of catalyst on viscosity, soap, and glycerin formation and biodiesel yield

In this study, different molar ratios of RBO and methanol are used for a proper chemical reaction. It is found from the experiment that with a molar ratio of 1:5 of RBO and methanol for different proportions of catalyst, the rate of production of biodiesel was not satisfactory. On the contrary, on using a molar ratio of 1:6, the rate of biodiesel production was satisfactory, although a certain amount of methanol was left unreacted. The effects of variation of catalyst percentage on viscosity, soap and glycerin formation, and biodiesel production are shown in Figures 4, 5, and 6. By varying the amount of catalyst (0.5, 1.0, 1.5, and 2.0%), the amount of glycerin and soap production was changed. For 0.5% catalyst (weight of the oil), the production of biodiesel was high compared with glycerin and soap production. The kinematic viscosity of biodiesel was 6.21 $mm^2/s$ (at 40°C), which was relatively higher than the ASTM standard. The same process was carried for 1, 1.5, and 2% catalyst (weight of the oil) and the kinematic viscosity was found to be 4.57, 4.45, and 4.11 $mm^2/s$, respectively, at 40°C. With increase in the amount of catalyst, the amount of soap was increased with decrease in water washing (to remove dissolved soap) period, which also decreased the total biodiesel production. Extraction of biodiesel from excessive soap and glycerin is also difficult. However, the data obtained for 0.9% catalyst show a promising improvement in higher biodiesel production rate with less soap and glycerin. It also reduced the water washing period with 0.5% catalyst use.

### Physicochemical properties of rice bran biodiesel

A comparison of physicochemical properties of rice bran biodiesel with ASTM D6751 with diesel is shown in Table 4. During further fuel properties test, it was observed that the biodiesel boiling point is 338°C for 2% catalyst use and 332°C for 0.9% catalyst use. This was in the range of the boiling point of diesel (range 180–360°C; source: Wiki). For 0.9% catalyst use, the flash point was determined to be higher than 170°C. A high flash point is necessary to eliminate the chance of self-ignition. The determined calorific value was about 39.957 MJ/kg. The calorific value was more than that of RBO.

### Projected estimation of biodiesel production from RBO

The estimated production of rice in Bangladesh in the year 2012–2013 was about 34 MMT (source: BBS). Assessing rice husk as about 20% of paddy, the amount of rice husk produced was 6.80 MMT. This rice husk contained about 16 to 32% of crude RBO of its weight (Lin et al. 2009). An estimate

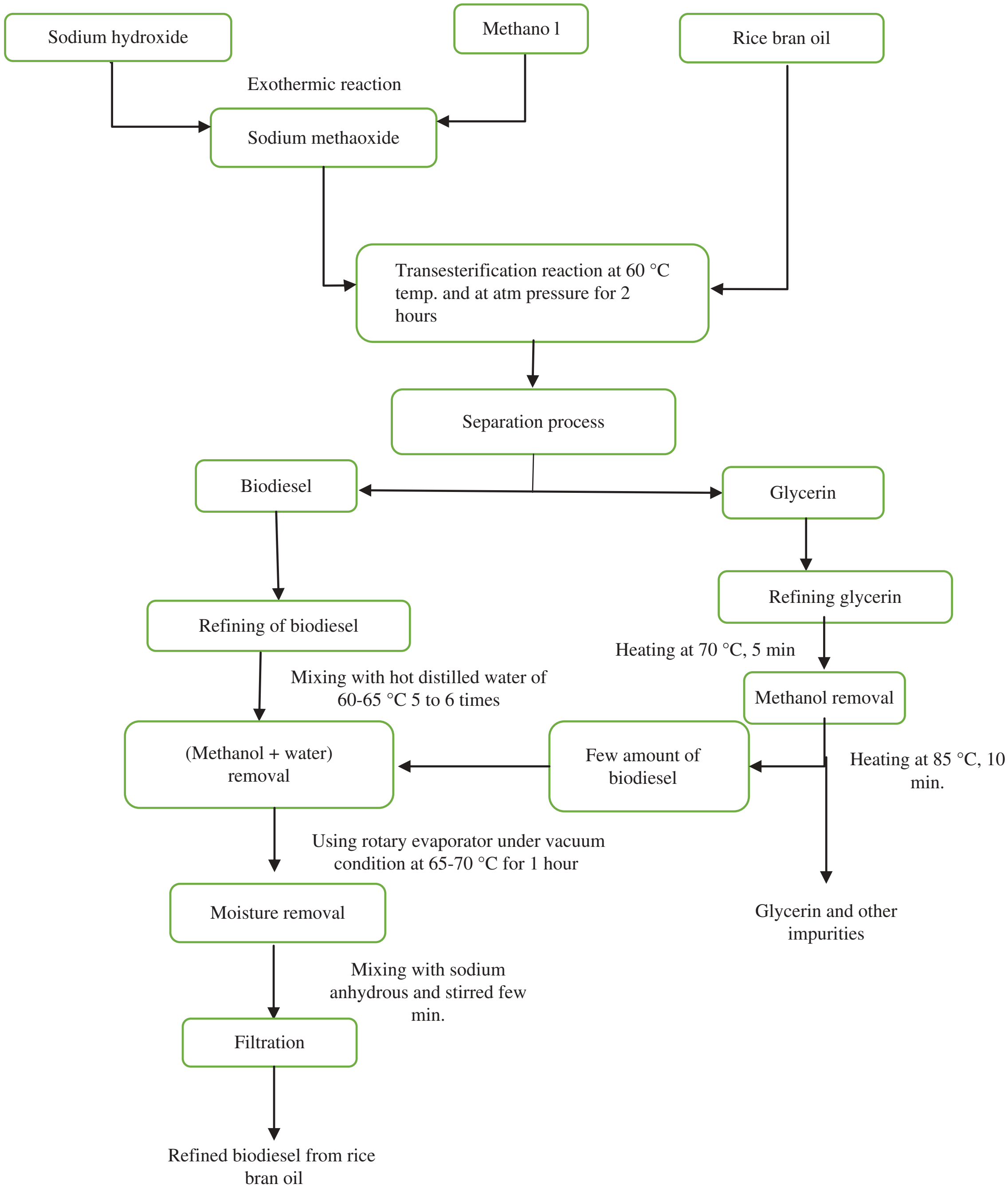


**Figure 2.** Flow diagram of production of biodiesel from RBO.

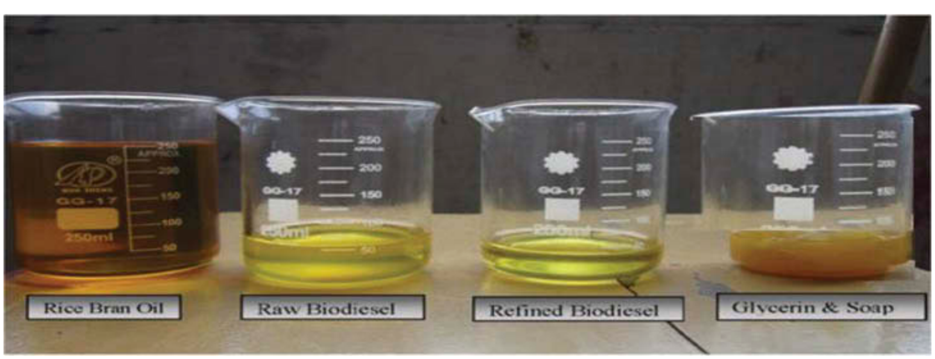


**Figure 3.** Different stages of RBO in biodiesel production.

Table 2. List of equipment used in the characterization of fuels.

| Property | Equipment | Manufacturer | Standard method | ASTM D6751 limit | Accuracy |
|---|---|---|---|---|---|
| Kinematic viscosity at 40°C | SVM 3000 – automatic | Anton Paar, UK | D445 | 1.9–6.0 | ±0.35% |
| Dynamic viscosity at 40°C | SVM 3000 – automatic | Anton Paar, UK | D7042 | n.s. | ±0.35% |
| Viscosity index | SVM 3000 – automatic | Anton Paar, UK | D2270 | | |
| Density at 40°C | SVM 3000 – automatic | Anton Paar, UK | D7042 | n.s. | 0.0005 g/cm$^3$ |
| Density at 15°C | DM40 LiquiPhysics™ density meter | Mettler Toledo, Switzerland | D4052 | | ±0.1 kg/m$^3$ |
| Flash point | Pensky-Martens flash point – automatic NPM 440 | Normalab, France | D93 | 130 min | ±0.1°C |
| Oxidation stability | 873 Rancimat – automatic | Metrohm, Switzerland | D675 | 3 h min | ±0.01 h |
| Higher heating value | C2000 basic calorimeter – automatic | IKA, UK | D240 | n.s. | ±0.1% of reading |
| Cloud point | Cloud and pour point tester – automatic NTE 450 | Normalab, France | D2500 | Report | ±0.1°C |
| Pour point | Cloud and pour point tester – automatic NTE 450 | Normalab, France | D97 | | ±0.1°C |
| CFPP | Cold filter plugging point – automatic NTL 450 | Normalab, France | D6371 | n.s. | |
| Acid value | G-20 Rondolino automated titration system | Mettler Toledo, Switzerland | D664 | 0.5 max | ±0.001 mg KOH/g |

n.s.: Not specified in ASTM test method

Table 3. Physicochemical characteristics of RBO.

| Property | Unit | Crude RBO |
|---|---|---|
| Kinematic viscosity at 40°C | mm$^2$/s | 52.225 |
| Dynamic viscosity at 40°C | m Pa.s | 47.364 |
| Density at 15°C | kg/m$^3$ | 924.3 |
| Specific gravity at 15°C | | 0.9251 |
| Kinematic viscosity at 100°C | mm$^2$/s | 10.393 |
| Acid value | mg KOH/g | 1.314 |
| Oxidation stability | h | 4.40 |
| Cloud point | °C | 0 |
| Pour point | °C | 0 |
| CFPP | °C | 16 |
| Higher heating value | MJ/kg | 39.548 |
| Viscosity index | | 192.8 |
| Refractive index | | 1.4718 |
| Transmission | %T | 87.1 |
| Absorbance | ABS | 0.06 |
| Flash point | °C | 300.5 |
| Moisture content | % | 0.11[a] |
| Ether insoluble matter (EIM) | % | 0.12[a] |
| Free fatty acid | % | 0.65[a] |
| Peroxide value | meq/kg | 0.87[a] |

[a]From supplier.

of about 1.36 MMT of crude RBO could be obtained annually according to an average of 20% oil content by weight. It is found from experiments that the use 0.9% catalyst provides maximum production, so according to this data, an estimated amount of 0.99 MMT of biodiesel was produced in the year 2012–2013. From the graph given in Figure 2, it could be unambiguously decided that without hampering the valuable land producing necessary human foods, selection of raw material for biodiesel production in Bangladesh must be rice bran. The prospect of rice bran for biodiesel production is shown in graph given in Figure 7; the graph shows raw material availability and projected estimation of biodiesel production for the year 2010–2011, 2011–2012, 2012–2013, and 2013–2014 (forecasted) with the rice production of 33.54, 33.70, 34, and 34.2 MMT, respectively (GAIN 2013).

## *Economic analysis*

In the present study, the production cost of biodiesel from rice bran was 473 Taka (Tk.)/L (approx. \$6.31/L), as shown in Table 5, because excess methanol was not recovered and the cost of refined RBO was high. If biodiesel is produced from rice bran on industrial level, not only can the production cost be reduced but the total production can also be increased. This will reduce the present production cost. Furthermore, byproducts from refining of crude RBO, such as wax, gum, and de-oiled rice bran, could be collected. The selling value of these byproducts would reduce the total production cost.

Table 5. Production cost of biodiesel from RBO for 0.9% catalyst.

| Component | Quantity | Rate (Tk.) | Used quantity | Amount (Tk.) |
|---|---|---|---|---|
| Refined and neutralized rice bran oil | 1 L | 150 | 1 L | 150 |
| Methanol (99.5% purity) | 2.51 L | 1800 | 255.2 mL | 183 |
| Catalyst NaOH (99.98% purity) | 500 gm | 700 | 8.216 gm | 11.5 |
| | | | Total | 344.5 |

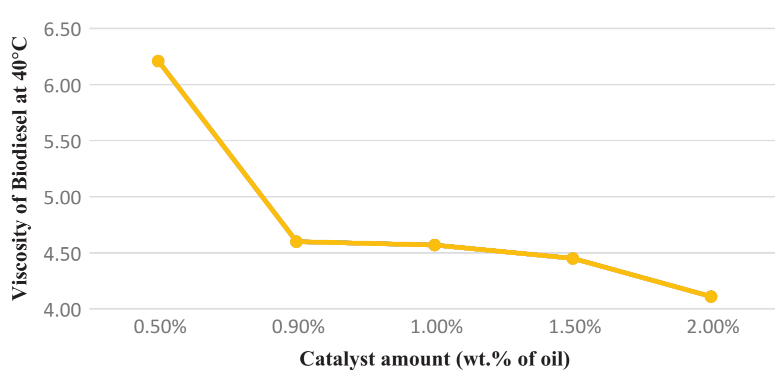


Figure 4. Graph of catalyst ammount vs. viscosity of biodiesel.

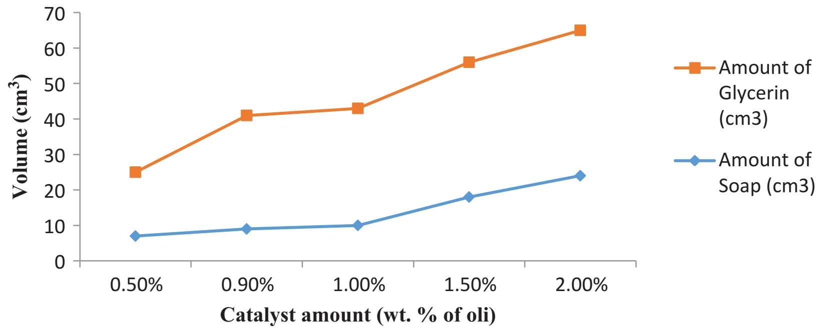


**Figure 5.** Graphs for catalyst amount vs. volume of glycerin and soap.

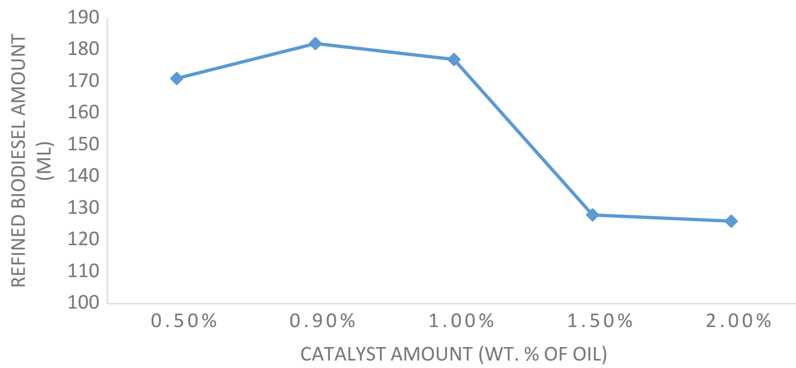


**Figure 6.** Graphs for catalyst amount vs. refined biodiesel amount.

**Table 4.** Physicochemical properties of RB biodiesel compared with diesel.

| Property | Unit | RB biodiesel | ASTM D6751 | EN 14214 | Diesel |
|---|---|---|---|---|---|
| Kinematic viscosity at 40°C | $mm^2/s$ | 5.3657 | 1.9–6.0 | 3.5–5.0 | 3.1818 |
| Dynamic viscosity at 40°C | m Pa s | 4.6581 | n.s. | n.s. | 2.6474 |
| Density at 15°C | $kg/m^3$ | 886.9 | n.s. | 860–900 | 0.8491 |
| Kinematic viscosity at 100°C | $mm^2/s$ | 1.9609 | n.s. | n.s. | 1.2723 |
| Acid value | mg KOH/g | 0.34 | <0.50 | <0.50 | |
| Oxidation stability | h | 3.58 | >3 | >6 | 58.51 |
| Cloud point | °C | 0 | Report | n.s. | 3 |
| Pour point | °C | −3 | n.s. | n.s. | 0 |
| CFPP | °C | 2 | n.s. | n.s. | 4 |
| Higher heating value | MJ/kg | 39.957 | n.s. | n.s. | 45.315 |
| Viscosity index | | 187 | n.s. | n.s. | 133.2 |
| Refractive index | | 1.4541 | n.s. | n.s. | N/D |
| Transmission | | 82.4 | n.s. | n.s. | N/D |
| Absorbance | | 0.08 | n.s. | n.s. | N/D |
| Flash point | °C | 174.5 | >130 | >120 | 73.5 |

n.s. = not specified, N/D = not determined.

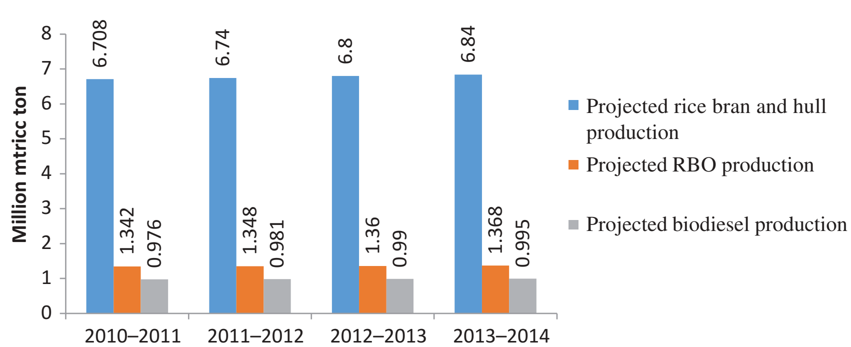


**Figure 7.** Graph for raw material availability and estimation of biodiesel production in Bangladesh.

Table 6. Data for different biodiesel production costs.

| Name of vegetable oil | Cost per liter oil (Tk.) | Cost of methanol (Tk.) | Cost of catalyst (Tk.) | Cost of biodiesel without methanol recovery (glycerin and soap) (Tk.) | Amount of biodiesel (L) | Total cost of biodiesel per liter (Tk.) |
|---|---|---|---|---|---|---|
| Jatropha[a] | 80.5 | 2305 | - | 2385.5 | 0.9 | 2650.5 |
| Neem[b] | 82.5 | 2160 | 11.0 | 2253.5 | 0.95 | 2372.1 |
| Castor[c] | 74 | 2160 | 30 | 2264 | 0.9 | 2515.55 |
| Sunflower[d] | 167.56 | 133.33 | 4.67 | 305.56 | 0.7 | 436.51 |
| Coconut[d] | 168 | 160 | 5.6 | 333.6 | 0.75 | 444.8 |
| Rice bran | 150 | 183 | 11.5 | 344.5 | 0.728 | 473.21 |

[a]Biodiesel from Jatropha oil as an alternative fuel for diesel engine, Dept. of Mechanical Engineering, **KUET**, March 2009.
[b]Biodiesel from Neem oil as an alternative fuel for diesel engine, Dept. of Mechanical Engineering, **KUET**, June 2012.
[c]Biodiesel from castor oil as an alternative fuel for diesel engine, Dept. of Mechanical Engineering, **KUET**, June 2012.
[d]Production of biodiesel from vegetable oil as an alternative fuel for diesel engine, Dept. of Mechanical Engineering, **KUET**, August 2013.

Table 7. Costing of residue.

| Component | Rate (Tk.) | Quantity | Amount Tk. |
|---|---|---|---|
| De-oiled rice cake | 11.81 | 4 kg | 47.25 |
| Soap and glycerin | 0.03 | 410 mL | 12.3 |
| Wax and gum | _[a] | _[a] | 20 (aprox.) |
| | | Total byproduct value | 79.55 |

[a]Data were not available.



### *Comparison of production cost with biodiesel produced from other sources*

From Table 6, it can be easily noted that the production cost of biodiesel from RBO compared with that from jatropha, neem, and castor oil is very low. At the same time, the production cost of biodiesel from RBO is close to that of sunflower and coconut oil. Therefore, we can conclude that with respect to production cost, rice bran has the prospect of producing biodiesel in Bangladesh.

### *Byproduct processing*

Rice bran wax has the properties close to that of carnauba wax. It is applicable in textile, cosmetic, pharmaceutical, and food industries. The de-oiled rice bran wax is widely used for making wax paper, carbon paper, and shoe polish. In the period from April 2012 to January 2013, India had exported 2 lakh ton of de-oiled RBO cakes, whose value was estimated at Rs. 175 crore. At this rate, the price of de-oiled rice bran cake in Bangladesh would be 11.81 Tk./kg (Re 1 = 1.35 Tk. = \$0.018). In addition, the selling value of byproduct glycerin and soap produced during biodiesel production from refined RBO can reduce the production cost. The use of B50 or B80 could also be a solution to reduce the cost. Table 7 shows the total byproduct value. So without methanol recovery, the production cost of biodiesel per liter comes to be 393.45 Tk. (473 − 79.55 Tk.) (or \$5.25, assuming \$1 = 75 Tk.).

## Conclusions

The primary objective of this project was to determine the prospect of rice bran for biodiesel production in Bangladesh. To achieve this objective, first the current energy scenario of Bangladesh and potential of rice bran for biodiesel production were analyzed. In the second stage, the appropriate and economical transesterification process was determined to obtain biodiesel, and the prospect of rice bran for biodiesel production with cost analysis was analyzed. We can conclude the following from this project:

The production rates of biodiesel differ with different amounts of catalyst. The highest production rate was obtained with 0.9% (wt% of oil) catalyst use.

We estimated that if the total produced rice bran was utilized, the projected estimation of biodiesel production in Bangladesh would have been nearly 1 MMT for the year 2012–2013, which is about half the diesel demand.

The fuel properties of biodiesel produced from RBO are very close to those of diesel, and its production cost is also lower or close to other biodiesel production costs.

The only disadvantage of produced biodiesel compared with the present cost of diesel in market is its high cost.

The farmlands are diminishing at a rapid rate, so without hampering human food security for biodiesel production, rice bran would be the right vegetable oil available all over Bangladesh.

In the present process, for small-scale production, the biodiesel production cost from rice bran seems to be high, but compared with cost of biodiesel production from other sources in Bangladesh, the prospect of rice bran would be high.

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## References

Ahmad, M., M. Zafar, H. Sadia, S. Sultana, M. Arshad, M. Irfan, and M. A. Khan. In press. Physico-chemical characterization of sunflower oil biodiesel by using base catalyzed transesterification. *International Journal of Green Energy*. doi:10.1080/15435075.2012.744312.

Aransiola, E.F., T.V. Ojumu, O.O. Oyekola, T.F. Madzimbamuto, and D. I.O. Ikhu-Omoregbe. 2014. A review of current technology for biodiesel production: State of the art. *Biomass and Bioenergy* 61:276–97.

Atabani, A.E., A.S. Silitonga, H.C. Ong, T.M.I. Mahlia, H.H. Masjuki, I. A.Badruddin, and H. Fayaz. 2013. Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production. *Renewable and Sustainable Energy Reviews* 18:211–45.

Bhatti, H., M. Hanif, U. Faruq, and M. Sheikh. 2008. Acid and base catalyzed transesterification of animal fats to biodiesel. *Iranian Journal of Chemistry and Chemical Engineering* 27(4) 41–8.

Biomass Energy Center. Agricultural residues. Website: http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,17302&_dad=portal&_schema=PORTAL.

BRTA. 2013. Registered vehicles in Bangladesh 2013. Website: http://www.brta.gov.bd/images/files/statistics/statistics-bangladesh-jan-16.pdf.

Cao, C.-y., and Y.-H. Zhao. 2012. Transesterification of castor oil to biodiesel using koh/nay as solid base catalyst. *International Journal of Green Energy* 10(2):219–29.

Danielski, L., C. Zetzl, H. Hense, and G. Brunner. 2005. A process line for the production of raffinated rice oil from rice bran. *The Journal of Supercritical Fluids* 34(2):133–41.

Einloft, S., T.O. Magalhães, A. Donato, J. Dullius, and R. Ligabue. 2007. Biodiesel from rice bran oil: Transesterification by tin compounds. *Energy & Fuels* 22(1):671–4.

Evangelista, João P.C., T. Chellappa, A.C.F. Coriolano, V.J. Fernandes Jr, L.D. Souza, and A.S. Araujo. 2012. Synthesis of alumina impregnated with potassium iodide catalyst for biodiesel production from rice bran oil. *Fuel Processing Technology* 104(0):90–5.

GAIN. 2013. GAIN report number: BG3004. In Website: http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Grain%20and%20Feed%20Annual_Dhaka_Bangladesh_3-28-2013.pdf.

Ghosh, M. 2007. Review on recent trends in rice bran oil processing. *Journal of the American Oil Chemists' Society* 84(4):315–24.

Hazir, S., and Amiruddin. 2012. *Global market study on Jatropha*, Project inventory Asia.Jennings, B.H., and C.C. Akoh. 2009. Characterization of a rice bran oil structured lipid. *Journal of Agricultural and Food Chemistry* 57(8):3346–50.

Institute of Energy Economics, Japan (IEEJ). 2012. Energy scenario of Bangladesh. Website: http://eneken.ieej.or.jp/data/4443.pdf.

Ju, Y.-H., and S. Zullaikah. 2013. Effect of acid-catalyzed methanolysis on the bioactive components of rice bran oil. *Journal of the Taiwan Institute of Chemical Engineers* 44(6):924–928 .

Ju, Yl.-l., and S.R. Vali. 2005. Rice bran oil as a potential resource for biodiesel: A review. *Journal of Scientific and Industrial Research* 64 (11):866.

Kafuku, G., M.K. Lam, J. Kansedo, K.T. Lee, and M. Mbarawa. 2010. Heterogeneous catalyzed biodiesel production from Moringa oleifera oil. *Fuel Processing Technology* 91(11):1525–9.

Lai, C.-C., S. Zullaikah, S.R. Vali, and Y.-H. Ju. 2005. Lipase-catalyzed production of biodiesel from rice bran oil. *Journal of Chemical Technology and Biotechnology* 80(3):331–7.

Li, Y.X., J.W. Yang, F.L. Hui, W.W. Fan, and Y. Yang. 2011. Optimization of biodiesel production from rice bran oil via immobilized lipase catalysis. *African Journal of Biotechnology* 10(72):16314–24.

Li, Q., J. Zheng, and Y. Yan. 2010. Biodiesel preparation catalyzed by compound-lipase in co-solvent. *Fuel Processing Technology* 91 (10):1229–34.

Lin, L., D. Ying, S. Chaitep, and S. Vittayapadung. 2009. Biodiesel production from crude rice bran oil and properties as fuel. *Applied Energy* 86(5):681–8.

Liu, Y., H. Wu, Y. Yan, L. Dong, M. Zhu, and P. Liang. 2012. Lipase-catalyzed transesterification for biodiesel production in ionic liquid [emim]tfo. *International Journal of Green Energy* 10(1):63–71.

Ma, F., and M.A. Hanna. 1999. Biodiesel production: a review. *Bioresource Technology* 70(1):1–15.

Mathiyazhagan, M., A. Ganapathi, B. Jaganath, N. Renganayaki, and N. Sasireka. 2011. Production of biodiesel from non-edible plant oils having high FFA content. *International Journal of Chemical and Environmental Engineering* 2(2):119–22.

Neethi Manickam, I., and P. Subramanian. 2006. Study of physical properties of coir pith. *International Journal of Green Energy* 3(4):397–406.

PetroBangla. 2014. At a Glance CNG activities in Bangladesh. Website: http://www.rpgcl.org.bd/exp_act.php?ltype=exp_glance.

Rizwanul Fattah, I.M., M.A. Kalam, H.H. Masjuki, and M.A. Wakil. 2014. Biodiesel production, characterization, engine performance, and emission characteristics of Malaysian Alezandrian laurel oil. *RSC Advances*4:17787–96.

Sadia, H., M. Ahmad, M. Zafar, S. Sultana, A. Azam, and M.A. Khan. 2012. Variables effecting the optimization of non-edible wild safflower oil biodiesel using alkali catalyzed transesterification. *International Journal of Green Energy* 10(1):53–62.

Samios, D., F. Pedrotti, A. Nicolau, Q.B. Reiznautt, D.D. Martini, and F. M. Dalcin. 2009. A transesterification double step process – TDSP for biodiesel preparation from fatty acids triglycerides. *Fuel Processing Technology* 90(4):599–605.

Thitsartarn, W, and S. Kawi. 2011. An active and stable CaO–CeO2 catalyst for transesterification of oil to biodiesel. *Green Chemistry* 13(12):3423–30.

Venkata S.G., and K. Raja Gopal. 2011. An experimental investigation on the performance and emission characteristics of a diesel engine fuelled with rice bran biodiesel and ethanol blends. *International Journal of Green Energy* 8(2):197–208. doi:10.1080/15435075.2010.548539.

Vijaya Lakshmi, Ch, K. Viswanath, S. Venkateshwar, and B. Satyavathi. 2011. Mixing characteristics of the oil–methanol system in the production of biodiesel using edible and non-edible oils. *Fuel Processing Technology* 92(8):1411–17.

Watanabe, Y., Y. Shimada, A. Sugihara, H. Noda, H. Fukuda, and Y. Tominaga. 2000. Continuous production of biodiesel fuel from vegetable oil using immobilized Candida antarctica lipase. *Journal of the American Oil Chemists' Society* 77(4):355–60.

Yi-Hsu J., and S.R. Vali. 2005. Rice bran oil as a potential resource for biodiesel: A review. *Journal of Scientific & Industrial Research* 64 (November):866–82.

Zullaikah, S., C.-C. Lai, S.R. Vali, and Y.-H. Ju. 2005. A two-step acid-catalyzed process for the production of biodiesel from rice bran oil. *Bioresource Technology* 96(17):1889–96.