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Review Article

Prospect of *Pongamia pinnata* (Karanja) in Bangladesh: A Sustainable Source of Liquid Fuel

P. K. Halder,[1] N. Paul,[2] and M. R. A. Beg[3]

[1] *Jessore University of Science & Technology, Jessore 7408, Bangladesh*
[2] *Bangladesh University of Engineering & Technology, Dhaka 1000, Bangladesh*
[3] *Rajshahi University of Engineering & Technology, Rajshahi 6204, Bangladesh*

Correspondence should be addressed to P. K. Halder; pobitra.halder@gmail.com

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Energy is the basic requirement for the existence of human being in today's digital world. Indigenous energy of Bangladesh (especially natural gas and diesel) is basically used in power generation and depleting hastily to meet the increasing power demand. Therefore, special emphasis has been given to produce alternative liquid fuel worldwide to overcome the crisis of diesel. *Pongamia pinnata* (karanja) may be an emerging option for providing biooil for biodiesel production. Although karanja biooil has been used as a source of traditional medicines in Bangladesh, it can also be used for rural illumination. This paper outlines the medical and energy aspects of *Pongamia pinnata*. It has been assessed that Bangladesh can utilize about 128.95 PJ through Pongamia cultivation in unused lands. The paper reviews the potentiality of *Pongamia pinnata* as a source of biodiesel and its benefits in Bangladesh. The paper also revives that, about 0.52 million tons of biodiesel can be produced only utilizing the unused lands per year in sustainable basis as it reduces CO_2, CO, HC, and NO_x emission compared to pure diesel.

1. Introduction

Pongamia pinnata (L.) Pierre (family: Leguminosae) is an important nonedible minor oilseed tree [1] that grows in the semiarid regions. It is probably originated from India and grows naturally in India, Bangladesh, Pakistan, Malaysia, Thailand, Vietnam, Australia, Florida, and Sri Lanka and also in northeastern Australia, Fiji, Japan, and the Philippines [2]. In the USA *Pongamia pinnata* was introduced into Hawaii in the 1960s by Hillebrand [3]. In Bangladesh it is popularly known as Koroch. It is an adaptable tree for tropical and subtropical regions which requires excellent drainage and a sunny location. In India, billions of karanja trees exist where karanja trees are cultivated commercially and seed is collected from December to April. However, in Bangladesh it is not cultivated commercially yet. In India, one person can collect 180 kg of seeds in 8 hours of a day where the collection cost is INR 4 per kg [4].

1.1. Classification

Kingdom: Plantae
Division: Magnoliophyta
Class: Magnoliopsida
Order: Fabales
Family: Leguminosae
Genus: *Pongamia*
Species: *pinnata*

Source: [5]

1.2. Botanic and Chemical Characteristics. *Pongamia pinnata* (chromosome number: 22) is a very fast-growing medium size plant with an average height of 30–40 feet and spreads canopy for casting moderate shade. *Pongamia pinnata* has a

Figure 1: Botanical feature of *Pongamia pinnata*: (a) karanja tree with green leaf, (b) flower morphology of karanja showing standard petal; about 25–35% of flowers set to seed, (c) elliptical karanja seed pods containing seed inside them, (d) karanja seeds which weigh about 2-3 g/seed and contain about 30–40% oil, and (e) karanja pod shells which weigh about 2 g/shell.

varied habitat distribution and can grow in a wide range of conditions. It can grow in various types of soil like salty, alkaline, hefty clay, sandy, stony, and waterlogged soils and also shows high tolerance against drought bearing temperature up to 50°C. The trunk is usually short with a diameter of more than 1.64 feet. The leaves are comprised of 5–7 leaflets 5–10 cm long and 4–6 cm wide which are arranged in 2-3 pairs. On the other hand, the bark is thin and gray to grayish-brown in color with yellow on the inside where the tap root is thick and long [6]. Pea-shaped flowers are generally 15–18 mm long and pink, light purple, or white in color [5]. The elliptical pods consist of single seed inside the thick walled pod shell which are 3–6 cm long and 2-3 cm wide as shown in Figure 1. The pods are dried in sun and the seeds are extracted by thrashing. Seeds are light brown in color with a length of 1.0–1.5 cm [5]. About 9–90 kg of seed pods can be obtained from one tree which yields up to 40% oil per seed and around 50% of this oil is C 18 : 1, which is considered as suitable for biodiesel production [7]. Another study shows that about 8–24 kg of kernels is obtained from one tree which yields 30–40% oil [8, 9]. The seeds naturally exist for about 6 months [10]. The air dried kernels consist of 19% moisture, 27.5% oil, 17.4% protein, 6.6% starch, 7.3% crude fiber, and 2.3% ash [9, 10].

1.3. Cultivation of Pongamia pinnata in Bangladesh. *Pongamia pinnata* is one of the few nitrogen-fixing trees which are predominantly cultivated easily through seeds. The genetic diversity has been conserved through storage of seeds which is the most common conventional and economical method [11, 12]. The growth of *Pongamia pinnata* is seen from sea level to an altitude of around 1200 m and an optimal annual rainfall of 500 to 2500 mm. The trees are naturally distributed along the coasts and riverbanks in lands and are native to the Asian subcontinent. Furthermore, these are also cultivated along roadsides, canal banks, and open farmlands. About $60 \times 60 \times 60\ cm^3$ pits are appropriate for planting where the spacing between rows should be 5 m and plant to plant distance is recommended to be 4 m [13]. Generally, three irrigations may be given in a year for better growth and development of the plants.

A simple and reliable method selection is the primary step for the successful propagation of *Pongamia pinnata* tree. However, coppicing and pollarding are considered as fruitful ways of agroforestry management practices for *Pongamia pinnata* [14]. The successful propagation methods of *Pongamia pinnata* are comprised of through seeds, through cuttings, and through layering and drafting. It can be easily propagated through seeds by direct sowing both in the nursery bed and in the polybags. However, seeds can be effectually used for mass propagation of *Pongamia pinnata* [15, 16]. A study shows the direct relationship between seed size and germination efficiency [17]. It can also be propagated through semihard wood stem cutting. Moreover, air layering and cleft drafting is the other process for successful propagation. The unused and marginal lands of Bangladesh can be brought under *Pongamia pinnata* cultivation to meet the need of liquid fuel.

2. Versatile Applications of *Pongamia pinnata*

Historically, all the parts of *Pongamia pinnata* like flower, seed, leaf, root, and so forth have been utilized as a source of traditional medicines, animal fodder, green manure, timber, fish poison, and fuel in India, Bangladesh, and other neighbouring regions.

2.1. Pongamia pinnata Wood. Traditionally, *Pongamia pinnata* wood is used as fuel in rural areas in Bangladesh. It has no distinct heartwood and varies from white to yellowish-grey color with a calorific value of 19.32 MJ/kg. The wood is considered as low quality timber due to its softness, tendency to split during sowing, and vulnerability to insect attack [6]. Therefore, the wood is used for stove top fuels, poles and ornamental carvings [18], cabinet making, cart wheels, posts [19], agricultural implements, tool handles, and some usual activities [20]. The ash produced from burning wood is used for dyeing [21].

2.2. Pongamia pinnata Oil. Oil is considered the most noteworthy product obtained from the *Pongamia pinnata* seeds. It is a thick, yellow or reddish-brown oil which has a calorific value of 40.756 MJ/kg, extracted through expeller, solvent extraction, and so forth. The oil is nonedible, acrimonious in taste, and offensive in smell and is used for commercial processes maybe as medicine and lamp fuel and for the production of biodiesel. Furthermore, it is used as fuel for cooking, as a lubricant, as water-paint binder, in leather dressing, and in soap-making, candles, and tanning industries [22]. Crude karanja oil (CKO) has also the application in body oils, salves, lotions, hair tonics, shampoos, and pesticides [23].

2.3. Pongamia pinnata as Fodder and Feed. The *Pongamia pinnata* leaves contain 43% dry matter, 18% crude protein, 62% neutral detergent fiber, and in vitro dry matter digestibility of 50% and are eaten by cattle and readily consumed by goats. The trees have a significant value in arid regions, however the use is not common. The deoiled cakes could be used as poultry feed and cattle feed [24].

2.4. Pongamia pinnata as a Medicine. Even though all parts of the plant are noxious, the flowers and fruits along with the seeds are used in many traditional medicines. Flowers are used to treat bleeding hemorrhoids whereas fruits aid treatment of abdominal tumors, ulcers, and hemorrhoids. Seed powder reduces fever and helps in treating bronchitis and whooping cough. On the other hand, leaves juices aid in treatment of leprosy, gonorrhea, diarrhea, flatulence, coughs, and colds. Besides, bark relieves coughs and colds and mental disorder. Root is used as a toothbrush for oral hygiene while root juice is used to clean ulcers [25]. *Pongamia pinnata* oil is styptic, anthelmintic, and good in leprosy, piles, ulcers, chronic fever, liver pain [26], and rheumatism arthritis scabies [27].

2.5. Seed Cake as Fertilizer. Seed cake, a byproduct of oil extraction, is bitter and unfit for animal feed. It is rich in protein and nitrogen and is used as green manure to fertilize the land. It is also used as a pesticide, especially against nematodes. Besides, the seed cake can be used for biogas production.

2.6. Soil Erosion. *Pongamia pinnata* trees are usually planted along the highways, roads, and canals to stop soil erosion. The plants develop a lateral network of roots for controlling soil erosion and binding sand dunes [28]. Thus, karanja plantation can reduce soil erosion with many other benefits as described.

3. *Pongamia pinnata*: A Viable Alternative to Liquid Fuel

Diesel and kerosene are considered as major liquid fuel and account for 90% of the country's total fuel. Thus *Pongamia pinnata*, a source of nonedible vegetable oil, is considered as the most significant to use as an alternative liquid fuel due to its nonfood use and less expense for production.

3.1. Alternative Oil for Kerosene. Kerosene, the most common liquid fuel, is traditionally used in rural illumination and for cooking purpose in Bangladesh. In the country, only about 49% of total population has access to electricity and has only few facilities to use LPG for cooking purpose. Therefore, population of remote and coastal areas use kerosene lamp and hurricane for lighting and the poor people of those villages use biomass burning stove for cooking and heating purposes. On the contrary, population of urban and semiurban areas use kerosene stove for cooking where LPG and biomass are not available. In the fiscal year 2012, the country has consumed about 508.5 million liters of kerosene as shown in Figure 2 [29]. The country imported about 124.28 million liters of kerosene in 2010 which was 24.41% of total consumed kerosene account as 509.24 million liters. Bangladesh Petroleum Corporation (BPC) has to pay USD 134.53 per barrel to import kerosene and jet fuel. BPC has planned to import 0.267 million tons of kerosene, jet fuel, and octane during the fiscal year 2013-2014. BPC is incurring loss of BDT 14–16 per liter for kerosene though the price is hiking.

Increasing price (68 BDT/liter) of kerosene is trending in reduction of kerosene consumption and encouraging finding out alternative liquid fuel option to kerosene. Furthermore, the reserve in the country is very limited. Hence, the consumption rate of kerosene is reduced by 37.42% from fiscal year 2001 to fiscal year 2012 though the demand is high. Recently, several techniques have been adapted to produce

Table 1: Comparison of *Pongamia pinnata* oil with other biomass derived oil and kerosene.

Variable	Pongamia seed [31]	*Jatropha curcas* [137]	Plum seed [138]	Mahogany seed [139]	Coconut seed [140]	Kerosene [30, 141]
Kinematic viscosity (cSt)	29.65[a]	52.76[a]	1.14[b]	3.8[b]	1.99[b]	2.71[c]
Density (kg/m^3)	912	932	940	1525	1095.5	780–810
Flash point (°C)	241	240	112	60	>100	37–65
HHV (MJ/kg)	40.756	39.774	22.4	32.4	21.40	46.2

[a]Value is at 30°C; [b]value is at 26°C; [c]value is at 20°C.

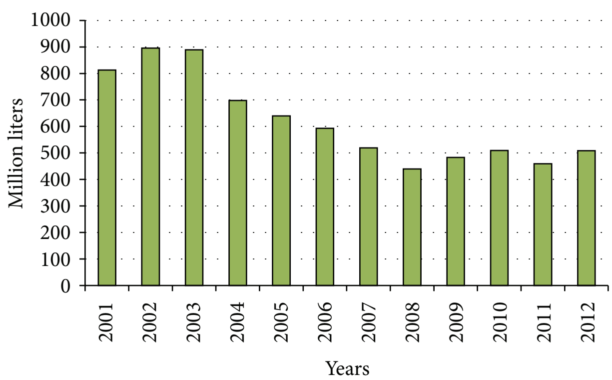

Figure 2: Kerosene consumption pattern in Bangladesh [29].

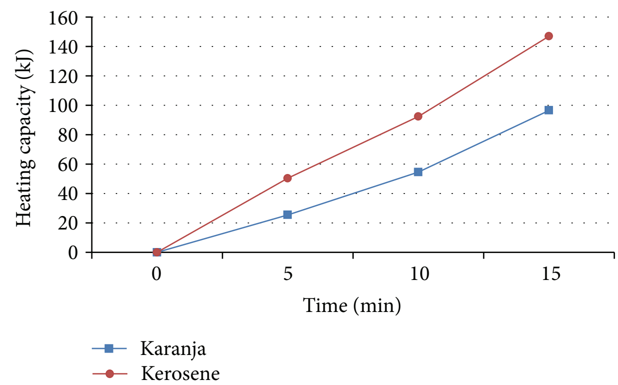

Figure 3: Performance characteristics of karanja and kerosene in gravity stove [31].

liquid fuels from nonedible seeds in renewable basis. Table 1 shows the comparison of some seed oils to kerosene. Kerosene has a calorific value of 46.2 MJ/kg with a density of 780–810 kg/m^3 [30] and a maximum distillation temperature of 205°C at the 10% recovery point. Among the seed oils *Pongamia pinnata* and *Jatropha curcas* have the competitive calorific value though the density is higher than kerosene. *Pongamia pinnata* has a calorific value of 40.756 MJ/kg [31] which is higher than other seed oils and slightly lower than kerosene.

Nonedible seed oil or straight vegetable oil (SVO) is rare to use in lighting and cooking due to its high density and viscosity. Hence, use of biooil in traditional kerosene stove for cooking and in wick-fed lamp for lighting shows the poor result due to its low capillary action. A recent study shows the effective way to use the crude karanja oil (CKO) for cooking purpose [31]. Use of karanja oil in gravity stove where fuel is feed under gravity shows the promising result as indicated in Figure 3 [31]. The oil also shows attractive heating performance in it though the method is not commercially well-known. Therefore, karanja oil may be an effective option for an alternative to kerosene.

3.2. Pongamia pinnata Biodiesel as an Alternative to Diesel. Diesel is an indispensable fuel generally used in industrial and agricultural goods transports, in vehicles, and in diesel tractors and pumps for irrigation. Bangladesh is a developing country with a total population of 150 million. The population of the country is growing rapidly which is creating the petro-diesel utilization sector.

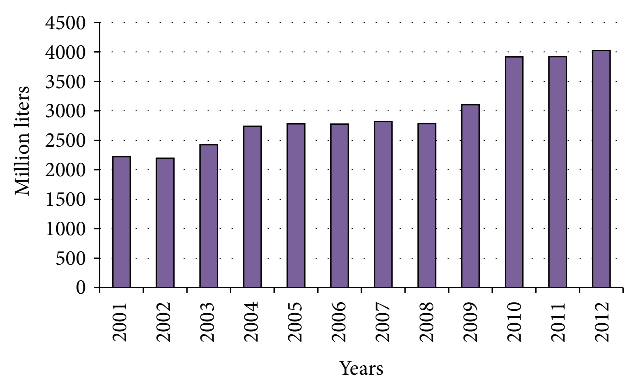

Figure 4: Diesel consumption pattern in Bangladesh [29].

In Bangladesh demand of diesel fuel is increasing day by day; hence it is necessary to find renewable alternative to diesel immediately. Not only Bangladesh's but also the world's diesel requirement is growing firstly. Bangladesh consumed about 4021.65 million liters of diesel in 2012 where the neighboring country India consumed about 66 million tons in 2011-12 [32]. Figure 4 shows the increasing trend of diesel consumption pattern in Bangladesh. The country has planned to import about 3 million tons of diesel where the country's average import is about 2.4 million tons [33]. The import price of diesel fuel is USD 133 per barrel and the government is incurring loss of BDT 13–15 per liter for diesel though the price has been increased to BDT 68 per liter.

TABLE 2: Comparison of Pongamia biodiesel to diesel and other fuels.

Analysis	Pongamia biodiesel [142]	Diesel [143]	Heavy fuel [144]	Fossil fuel [142]
Kinematic viscosity (cSt)	5.867	2.61	200	2–5
Density (kg/m^3)	870	827.1	980	820–860
Flash point (°C)	186	53	90–180	35 min
HHV (MJ/kg)	39-40	45.18	42-43	44.03

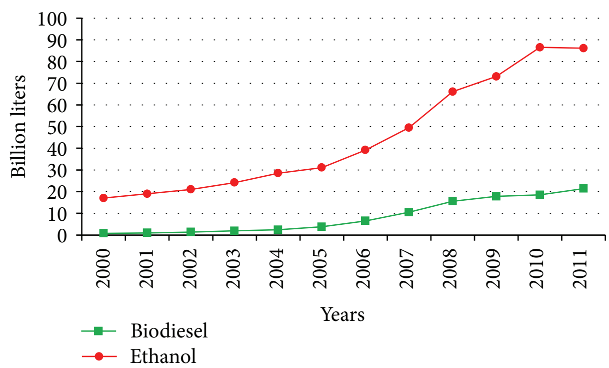

FIGURE 5: Worldwide biofuel production scenario [35].

Considering the increasing prices and environmental aspects of fossil fuels especially diesel fuel, interests have been revived around the world to find renewable substitute for fossil fuels. Biodiesel obtained from vegetable oils is considered the most suitable alternative to diesel around the world [34]. World's biofuel production has been growing rapidly to meet the increasing demand of petrodiesel and has reached 107.5 billion liters in 2011 comprising 21.4 billion liters of biodiesel and 86.1 billion liters of ethanol as shown in Figure 5 [35]. The USA, Germany, Brazil, Argentina, and France are the world's top biodiesel producer countries where the USA has increased the biodiesel production mainly from soybeans by 159% to nearly 3.2 billion liters in 2011 [35]. However, Indonesia, Malaysia, Thailand, the Philippines, and India are the largest biofuel producing countries in Asia [36].

Various vegetable oils like coconut, jatropha, karanja, rapeseed, peanut, sunflower, and soybean have been used to produce biofuel for the last few years [37]. In the year 1910, Dr. Rudolf Diesel first introduced peanut oil as fuel in compression ignition (CI) engine [38]. However, high viscosity, low volatility, and polyunsaturated character of SVO are the foremost problems of using it as substitute for diesel in CI engine [39]. The processed vegetable oil (biodiesel) obtained through transesterification solves the problems associated with SVO and can be used in CI engine [40]. Numerous researchers have showed the effective use of plant oil derived biodiesel as fuel in CI engines [39, 41–43].

Of the plant seeds, karanja is considered the most attractive source for biodiesel production due to its renewable, safe, and nonpollutant nature. Furthermore, it is cost-effective and diverse feedstock for biodiesel due to its higher recovery and quality than other seeds, no direct competition with edible food crops and with current farmland. The properties of biodiesel prepared from karanja oil are presented in Table 2.

Some researchers have tested the suitability of *Pongamia pinnata* oil as SVO in CI engine [44, 45]. Other studies have shown that the potentiality of *Pongamia pinnata* oil as a source of raw material for the production of biodiesel is well established [46–51]. However, some of them have mentioned the suitability of CKO compared to jatropha due to its less toxicity and economy [48–50]. In Bangladesh, a study has indicated the biodiesel production from CKO and its effective use in CI engine as diesel substitute [52]. Karanja biodiesel has no corrosion on piston metal whereas jatropha biodiesel has slight corrosive effect.

It has been estimated that approximately 550 karanja trees are planted in one hectare which yield about 7.7 tons of seeds and 1.8095 tons of oil [53]. It is considered that about 90% biodiesel is obtained through transesterification of karanja oil [54]. Hence, one hectare yields about 1.62855 tons of biodiesel. Bangladesh has a total marginal length of 4246 km comprised of 4053 km with India and 193 km with Myanmar [55]. Moreover, the country has about 0.32 million hectares of unused land [56]. Considering plant to plant spacing as 4 m, only marginal land of the country has a potentiality of planting about 1061501 plants which yield 3.49 kilotons of oil. Accordingly, expected biodiesel production in Bangladesh from karanja oil is estimated to be about 0.52 million tons per year utilizing the unused land. Hence, the country can reduce the import of diesel fuel by 21.67% ($(0.52 \times 100)/2.4 \approx 21.67\%$) which will save approximately 508.53 million USD. Therefore, karanja can play an emerging role in the sector of liquid fuel.

3.2.1. Need of Biodiesel in Bangladesh Context. Liquid fuel especially diesel is the key input for the development of each and every sector in developing countries like Bangladesh. Excessive requirement of diesel in transport and power sector in Bangladesh forces to find alternative option. Biodiesel is considered as the prominent one due to the following reasons:

(i) It is needed for rapid depletion of fossil fuels and hikes in oil prices.

(ii) Biodiesel is a renewable and less polluting source of energy.

(iii) It is considered as ecofriendly and nontoxic.

(iv) Biodiesel industry can strengthen the domestic, rural, and agricultural economy.

(v) Biodiesel has positive energy balance ratio and can be used in CI engines.

(vi) It reduces import of petroleum products.

Table 3: Energy potential of karanja in Bangladesh.

Energy items	Quantity (ton ha^{-1} $year^{-1}$)	Reference	Calorific value (GJ/ton)	Reference	Energy content (GJ ha^{-1} $year^{-1}$)	Energy potential in Bangladesh (PJ $year^{-1}$)
Fuel wood	5	[57]	19.25	[57]	96.25	30.8
Biodiesel	1.62855	[53, 54]	38.00	[145]	61.8849	19.8
Glycerin	0.18095	[53, 54]	18.05	[146]	3.2661	1.05
Seed cake	5.8905	[53]	18.98	[145]	111.8017	35.78
Pod shell	8.65	[58]	15	[145]	129.75	41.52
Total	—	—	—	—	402.9527	128.95

4. Energy Assessment of *Pongamia pinnata*

Like other trees, karanja has an enormous energy potential which comprises the energy of wood, energy of pod shell, energy of biodiesel, energy of glycerin, and energy of seed cake. It has been estimated that about 5 tons of fuel wood can be obtained from one hectare per year which has a calorific value of 19.25 MJ/ton [57]. One hectare can provide about 7.7 tons of seeds which yield 1.8095 tons of oil and 5.8905 tons of seed cake [53]. Furthermore, the seed cake can be utilized for biogas production and biogas slurry can be used as organic fertilizer. Considering 90% conversion factor about 1.62855 tons of biodiesel is estimated from oil and the remaining byproduct is glycerin which accounts for 0.18095 tons as shown in Table 3. Besides, one hectare produces about 8.65 tons of pod shell [58]. Total energy content of karanja per hectare was calculated by considering the calorific value of each item and estimated to be about 402.95 GJ/year. Accordingly, Bangladesh can utilize 128.95 PJ energy per year from karanja which is equivalent to 4.4 million tons of coal.

Table 4: Emission characteristics of biodiesel on engine performances.

Variable	Emission status	Reference
PM	Increase	[61, 100, 114–116, 124, 125]
	Decrease	[62–69, 80–83, 85, 94, 95, 101–107, 119–123]
HC	Increase	[96, 114, 115]
	Decrease	[63, 65, 67–69, 80–82, 84–86, 95, 100–105, 107–112, 117, 118, 121–123, 126, 127]
NO_x	Increase	[62, 63, 65, 67–73, 80, 83, 85, 86, 101, 107, 109–113, 117, 120, 126, 128–130]
	Decrease	[61, 64, 66, 81, 92, 97, 100, 103, 105, 114, 115, 118, 123, 126, 131–136]
CO	Increase	[96, 107, 114–118]
	Decrease	[61–64, 66–71, 73, 81, 83, 84, 93–95, 100–113, 128]
CO_2	Increase	[67, 94–98]
	Decrease	[63, 64, 73, 82, 83, 92, 93]

PM: particulate matter, NO_x: nitrogen oxides, CO: carbon monoxide, HC: hydrocarbon, and CO_2: carbon dioxide.

5. Engine Performance and Emission Analysis

In recent days, global warming is the foremost concern endorsed due to the large-scale use of fossil fuels. The use of vegetable oil ester which is biodiesel in CI engine shows the promising engine performance comparable with diesel fuel [59]. Besides, biodiesel is basically sulfur-free and emits considerably fewer particulates, hydrocarbons, and less carbon monoxide than conventional diesel fuel [32]. However, emissions of NO_x from biodiesel are slightly higher than diesel in CI engines [60]. Table 4 presents the summery of various emission statuses from biodiesel.

Many researchers have investigated the performance and emission characteristics of biodiesel in CI engine as a substitute for diesel fuel. Reduction in the power of CI engine due to the loss of heating value of biodiesel was reported in [61–79]. Some other researcher found no substantial variation between diesel and biodiesel performance in CI engine [80–84]. However, astonishing power increase due to use of pure biodiesel was noticed by [85, 86]. Karanja methyl ester (KOME) B100 which reduces the brake thermal efficiency of CI engine was investigated by some researcher [87, 88]. Minor difference between the engine efficiency of using KOME and pure diesel was found in [89, 90]. Surprisingly, high brake thermal efficiency due to use of B20 KOME was observed by [91]. However, a study in Bangladesh showed the most promising result in CI engine performance with B25 and B100 KOME competitive to pure diesel as presented in Figure 6 [52].

Emission from CI engine is a concerning matter which is reduced by using biodiesel as substitute for pure diesel. Researches [63, 64, 73, 82, 83, 92, 93] revealed the reduction in CO_2 emission from CI engine with use of biodiesel. However, some researchers found an increase of CO_2 emission [67, 94–98], while, in literatures [73, 82], it was reported that biodiesel resulted in about 50–80% reduction in CO_2 emissions compared to diesel fuel. Table 5 presents the comparative summary of CO_2 emission from various fuels.

KOME biodiesel which resulted in reduction of CO_2 emission was presented in [90, 91] as shown in Figure 7 [91]. Karanja oil reduces the overall effect of CO_2 emissions by about 75% as it absorbs about 30 tons of CO_2 per hectare per year [99].

Many literatures [61–64, 66–71, 73, 81, 83, 84, 93–95, 100–113] reported the decreasing nature of CO emission from

Table 5: Emission of CO_2 per unit item.

Fuels	CO_2 emission (kg/kg fuel)	Reference
Biomass	1.19	[147]
Bituminous coal	2.46	[147]
Natural gas	1.93	[147]
Diesel	3.35	[148]
Biodiesel	0.67–1.675	[73, 82]

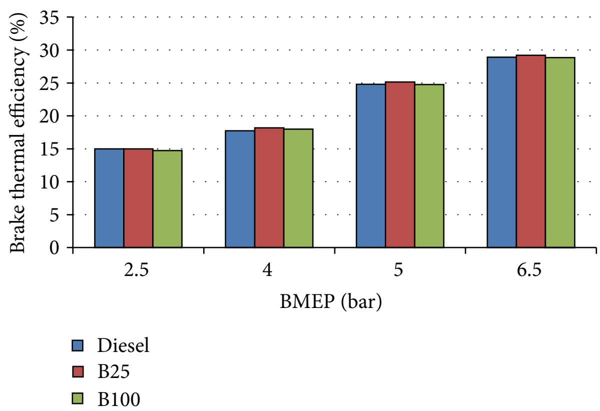

Figure 6: Brake thermal efficiency of CI engine with diesel fuel, B25, and B100 KOME [52].

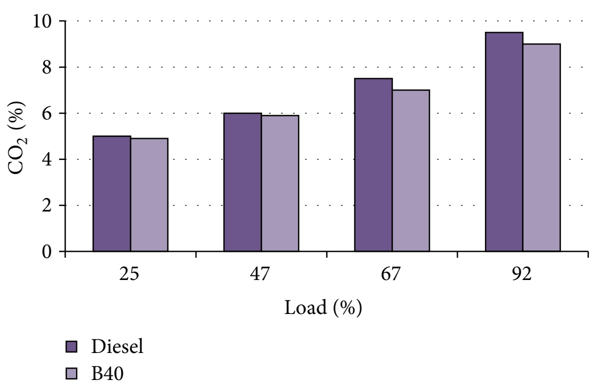

Figure 7: CO_2 emission of CI engine with diesel fuel and B40 KOME [91].

biodiesel as CI engine fuel, whereas some researchers [96, 107, 114–118] observed the rise of CO emission. It was found that B100 KOME biodiesel reduces about 73–94% CO emission [66]. Besides, [52, 87, 89] agreed that KOME biodiesel reduces the CO emission as illustrated in Figure 8 [52]. Numerous studies also showed that biodiesel reduces PM emission in CI engine [62–69, 80–83, 85, 94, 95, 101–107, 119–123]. On the contrary, few reported the increase of PM emission [61, 100, 114–116, 124, 125].

It is predominantly investigated that use of biodiesel instead of pure diesel resulted in reduction of HC emission [63, 65, 67–69, 80–82, 84–86, 95, 100–105, 107–112, 117, 118, 121–123, 126, 127]. However, a very few number of

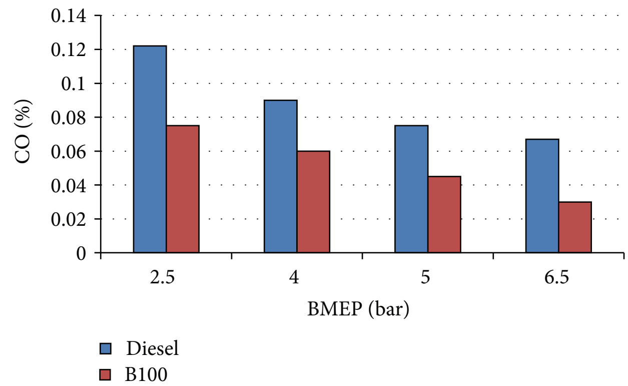

Figure 8: CO emission of CI engine with diesel fuel and B100 KOME [52].

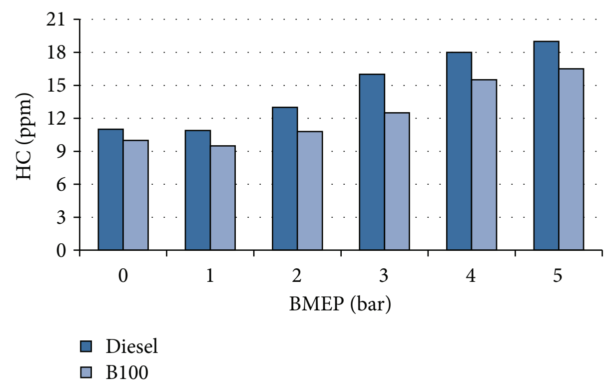

Figure 9: HC emission of CI engine with diesel fuel and B100 KOME [87].

researchers noticed the increase of HC emission [96, 114, 115]. Approximately 63% of HC emission was reduced by using biodiesel compared to pure diesel fuel [97]. KOME biodiesel reduces the HC emission in CI engine [87, 89, 91] as shown in Figure 9 [87].

In many studies [62, 63, 65, 67–73, 80, 83, 85, 86, 101, 107, 109–113, 117, 120, 126, 128–130], it was reported that biodiesel causes the increase in NO_x emission. On the other hand, reduction of NO_x emission was presented in [61, 64, 66, 81, 92, 97, 100, 103, 105, 114, 115, 118, 123, 126, 131–136]. However, [52] observed a maximum of 15% increase in NO_x emissions for B100 KOME as presented in Figure 10 [52]. Besides, [87, 91] noticed the increasing trend wherein [89] noticed the decreasing trend of NO_x emission.

6. Rural Development in Bangladesh through *Pongamia pinnata*

The *Pongamia pinnata* system can play a pivotal role for the socioeconomic development of rural areas in Bangladesh. Cultivation of *Pongamia pinnata* covers the following main aspects of rural developments in the country:

(i) creation of job sector for rural unemployed people basically for women,

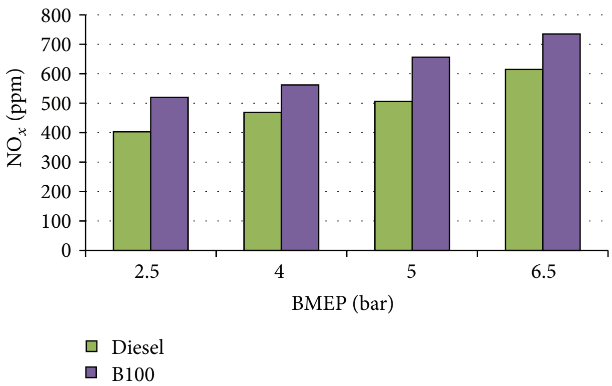

Figure 10: NO_x emission of CI engine with diesel fuel and B100 KOME [52].

(ii) increase of agricultural works like planting, weeding, and oil extraction,

(iii) opportunity of developing small size rural industry,

(iv) reduction of uncultivated lands through *Pongamia pinnata* plantation,

(v) increase of per capita income of rural people through biodiesel production,

(vi) energy supply for rural illumination and fuel for small stationery engines,

(vii) reduction in fossil fuel importing bill through biodiesel production.

7. Concluding Remarks

Pongamia pinnata, a versatile resource, shows the promising properties for the medical and biodiesel production industry. Many countries in the world are producing biodiesel in order to replace the fossil diesel fuel. Bangladesh has a considerable potential of biodiesel production from karanja as it has high growth rate in Bangladesh. The country has about 0.32 million hectares of unused lands which yield about 0.52 million tons of biodiesel per year and can reduce import of diesel fuel approximately by 21.67%. Besides, on energy basis country's unused lands provide about 128.95 PJ from karanja equivalent to 4.4 million tons of coal. However, the country has not started commercial cultivation of Pongamia yet. Furthermore, Pongamia biodiesel is environmentally friendly and causes fewer CO_2, CO, HC, and NO_x emission in CI engine as an alternative fuel to diesel. Karanja biodiesel blends of 20% with fossil diesel fuel produce approximately 70% less pollution. In conclusion, Bangladesh should take initiative to cultivate Pongamia and other nonedible seed plants for biodiesel production.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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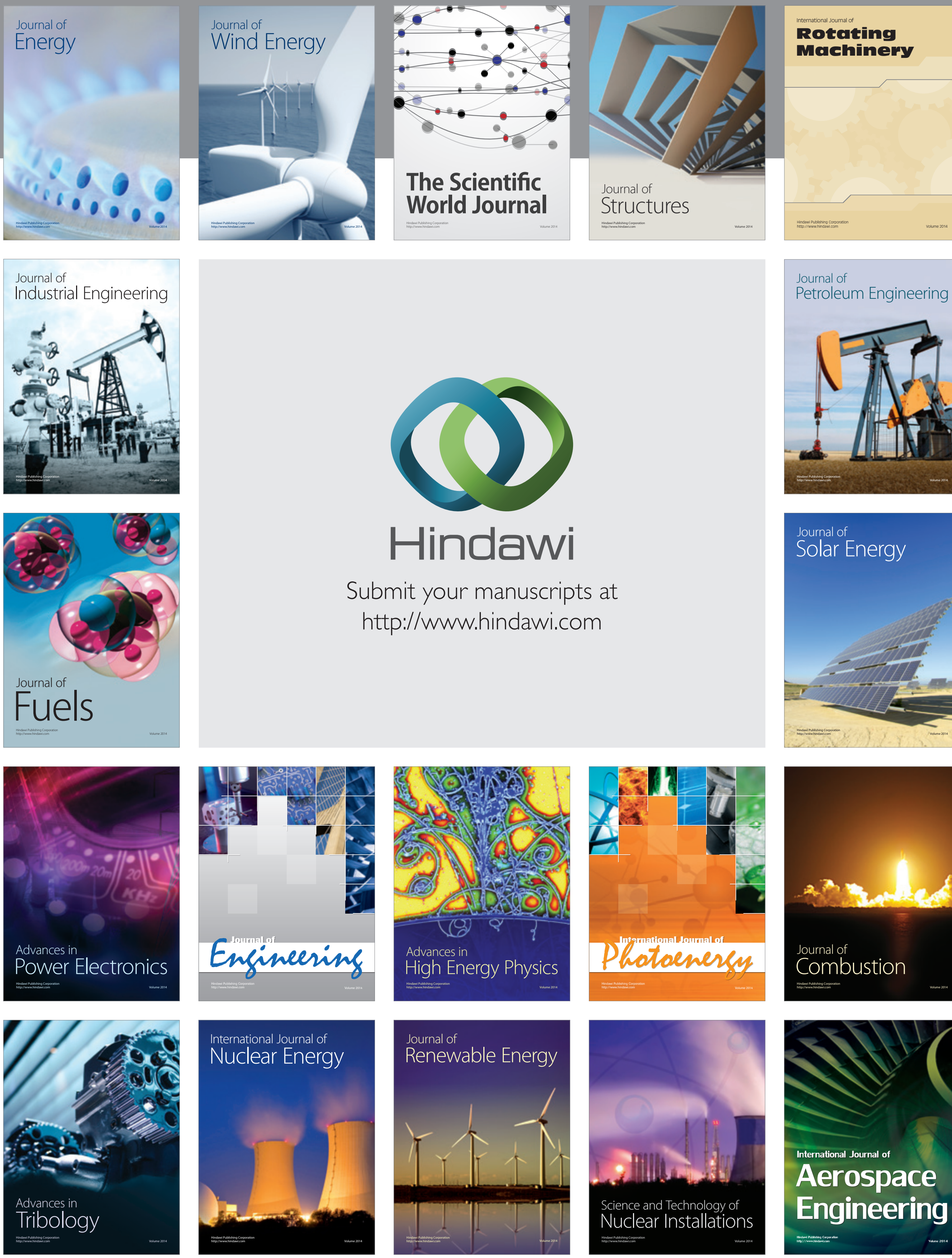
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