Chapter

Koroch (*Pongamia pinnata*): A Promising Unexploited Resources for the Tropics and Subtropics

Abul Kalam Mohammad Aminul Islam, Swapan Chakrabarty, Zahira Yaakob, Mohammad Ahiduzzaman and Abul Kalam Mohammad Mominul Islam

Abstract

The demand of petroleum fuel is increasing day by day. To meet up the energy demand, people of developing countries like Bangladesh basically used energy from indigenous sources, which are reducing quickly. Hence, it should be emphasized to explore unconventional fuel to overwhelm the crisis of petroleum fuels. Koroch (*Pongamia pinnata* L. Pierre) is a quick-growing leguminous tree that has the ability to grow on marginal land. Higher oil yield as well as physicochemical properties increases the suitability of using *Pongamia* as a promising substitute for supplying feedstock of biofuel production. Besides biofuel production, *P. pinnata* has multi-purpose uses as traditional medicine to animal feed, bio-pesticides, and bio-fertilizers. A better understanding and knowledge on the ecological distribution, botanical characteristics, physiology, and mode of reproduction along with physicochemical properties, and biosynthesis of oil is essential for sustainable production of biofuel from *P. pinnata*. In this chapter, we discuss overall biological and physicochemical properties as well as cultivation and propagation methods that provide a fundamentals for exploiting and improving of *P. pinnata* as a promising renewable source of biofuel feedstock.

Keywords: *Pongamia pinnata*, biofuel crops, underutilized, agriculture, environment

1. Introduction

Koroch (*P. pinnata*) is the member of Leguminosae family and Papilionoideae, more specifically the Millettieae tribe [1]. It is an oil seed tree known for its versatile applications but still remain unexploited. It is medium-sized, drought resistant, fast-growing, nitrogen fixing leguminous tree or glabrous shrub (15–25 m tall). It has been delineated as briefly deciduous or evergreen with a broad canopy of drooping or spreading branching behavior [2]. *P. pinnata* has a broadly distribution across coastal and riverine areas, primarily in humid tropical and subtropical environment of Indian subcontinent, Asia, Africa, Pacific, and America. It is found that the center of origin for *Pongamia* is most likely India (**Figure 1**) [3]. In the USA,

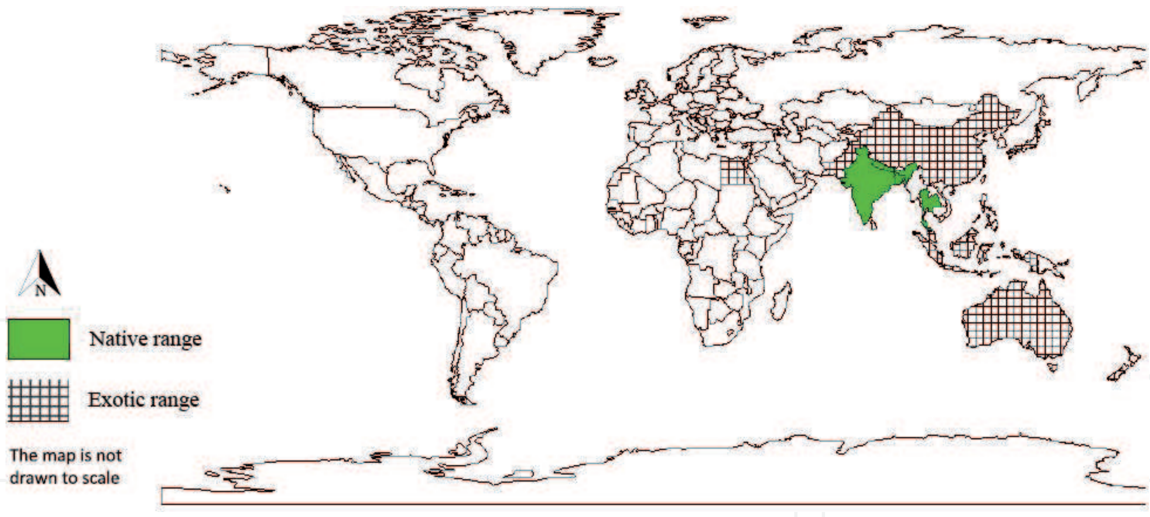

Figure 1.
Distribution of P. pinnata. *The species has been planted in the above shown countries on the map. It does not indicate that the species can be planted in every ecological zone within that countries or in other countries than those depicted. Source: Agroforestry database 4.0 [2].*

P. pinnata was introduced into Hawaii in the 1960s by Hillebrand. It is also found in the Andaman and Nicobar Islands, Bismarck, Archipelago, Northern Marianas, Djibouti, Tanzania, Zaire, Uganda, Caribbean, and Nicaragua. Traditionally, Koroch has been utilized in Indian sub-continent and neighboring countries as folk medicines, green manure, animal fodder, wood, and poison for fish and fuel [4, 5]. It is also used in agriculture and management of environment as fungicide, insecticide, nematicide [6], and soil improver as it fixes atmospheric nitrogen [1, 7]. *Pongamia* has bio-ameliorative capacity which adds nitrogen, phosphorous, potassium, and organic carbon to soil. It also improves the rural economic condition by engendering employment opportunities during different phases of cultivation and further processing.

As the reserve of non-renewable fossil fuel become declining, the society is increasingly aware of the alternate source for the production of fuels. Now it is discernible that biofuel has substantial contribution to the future energy demands both for domestic and industrial economics. For production of biofuel, USA and some European countries are looking for various vegetable oils such as soybean, rapeseed, and sunflower oil but these are edible in nature [8, 9]. Developing countries like Bangladesh, India, and some Asian countries cannot provide edible oil as fuel alternative. But some non-edible species such as Koroch (*P. pinnata*), Jatropha (*Jatropha curcas*), castor (*Ricinus communis*), neem (*Azadirachta indica*), etc. can be utilized as alternate fuel sources. Among these, *P. pinnata* has high potentiality for extraction of seed oil for manufacturing biodiesel. *Pongamia* seed comprises 30–40% oil that can be utilized as biodiesel through transesterification [10, 11]. It has the potentiality to provide a renewable energy resource and mitigate the competitive situation of the use of food crops as biofuel as it can be cultivated on marginal lands. Further research is needed into different areas of production and utilization of this species as a source of biodiesel [1, 12, 13]. Identification and evaluation of elite genotypes has been very limited for the production of seed and its oil content. To increase the biodiesel production, selection of elite genotypes for economically important traits such as high seed yield, high oil content, and desirable fatty acid composition is the pre-requirement [14]. Finally, large scale plantation of clonal stocks of elite genotypes needs to be done through encouraging afforestation programs. The overall objective of this chapter is to encourage exploiting these promising resources for sustainable biofuel production by updating knowledge on the ecological and botanical characteristics, cultivation and propagation techniques and physicochemical properties and biosynthesis of *Pongamia* oil.

2. Ecological, botanical and cultural characteristics

2.1 Ecology of *P. pinnata*

P. pinnata is native to humid tropical and sub-tropical region. Areas having annual rainfall ranging from 500 to 2500 mm and maximum temperature 27–38°C and the minimum from 1 to 16°C is suitable for cultivation. Although it requires rain, trees need a dry season of 2–6 months. Probably, it ranges from Tropical Dry to Moist through Subtropical Dry to Moist Forest Life Zones [15, 16]. The trees also can cope with adverse climatic and soil moisture conditions and naturally generate in lowland forest on limestone and rocky coral outcrops on the coast, along the border of mangrove forest and along tidal streams and rivers. Mature trees can stand against water logging and slight frost, also counteract to high winds, draught, and salinity but are susceptible to freezing temperatures [17–19]. This species grows at altitude ranges from 0 to 1200 m, but in the Himalayan, foothills is not found above 600 m [2, 20]. It has been considered as a "maritime species" since it tends to grow naturally along coasts and riverbanks in India, Bangladesh, and Myanmar [16, 21]. *P. pinnata* can be grown in wider soil types ranging from stony to sandy to heavy swelling clay soils including oolitic limestone, but it exhibits best growth in deep, well-drained and sandy loam soils with certain moisture, but it does not grow well on very dry sands, although it tolerates saline conditions, alkalinity, and waterlogged soils even with its root in fresh or salt water [2]. If *Pongamia* grown on soils with a pH above 7.5, it will show nutritional deficiencies [22].

2.2 Botanical characteristics

The odd pinnately compound leaves with long slender leaf stalk are fixed up alternately and consist of 5–9 leaflets that are ovate elliptical or oblong (5–25 cm × 2.5–15 cm), obtuse-acuminate at the tip, rounded to cuneate at the base, not toothed at the edges and slightly thickened. The leaflets are settled in two or three pairs except largest terminal leaflet. In juvenile stage, leaves remain without hair and pinkish red in color and turn into glossy dull green above and dull green with prominent veins at maturity [2]. The raceme type inflorescence is 6–27 cm long, axillary, pendant and it has pairs of strongly balsamic flowers which are fascicled (2–4 together), short stalked and pea shaped (15–18 mm long). The calyx is campanulate, truncate (4–5 mm long), short dentate, lowermost lobe, sometimes longer and the corolla is white to pink, purple inside and brownish veins on the outside and five-toothed. The standard is sub-orbicular (1–2 cm), broad with basal auricles often with a green blotch and thin silky hair on the outside. The wings are oblong, oblique with a slightly adherent to obtuse keel. The stamens are monadelphous, vexillary stamen free at the base but jointed with others into a close tube. The ovary is sub sessile to short-stalked and pubescent and there are usually two ovules (rarely three). The style is filiform, upper half incurved and glabrous, and the stigma is small and terminal [2, 23].

Pods are short stalked, smooth, flattened but slightly swollen, oblique-oblong to ellipsoid (3–8 cm × 2–3.5 cm × 1–1.5), brown, thick-walled and leathery to sub-woody, reniform, hard, and indehiscent. It contains 1–2 seeds which are elliptical or compressed ovoid, bean-like, with a brittle coat (1.5–2.5 cm × 1.2–2 cm × 0.8 cm), flattened, dark brown, and oily. The bark is thin gray to grayish-brown with smooth or faint vertical crevasse and yellow in the inside [24]. The branchlets are hairless with prominent pale stipule scars. The lateral roots are legionary, and the taproot is thick and long which is expanded about 10 m into the ground to uptake water from far beneath the ground surface without competing with other crops [2] (**Figure 2**).

2.3 Reproductive biology and propagation

In *P. pinnata*, mature buds open during 07:00–10:00 h with peak anthesis at 08:00 h and all the 10 anthers dehisce by longitudinal slits in mature bud stage. It happens approximately 3h prior to anthesis. The number of pollen grains per anther is 2785 ± 266 and per flower 27,850 [25]. The prevailing environmental condition such as temperature, relative humidity, rainfall, etc. also attributed with the time of anthesis. The style is solid with central core of transmitting tissue in *P. pinnata*. Stigma receptivity may greatly caliber the rate of pollination success [26]. Raju and Rao [25] reported that in *P. pinnata*, the stigma receptivity is brought about 1 hour after anther dehiscence, but strong receptivity occurs during 09:00–16:00 h. The flowers start to concatenate gradually from 17:00 h onwards and close completely at 18:00 h. The closure of flower indicates by gradual movement of the standard petal to enclose the wing and keel petal completely. The closed flowers remain permanent which is analogous to mature buds. In pollinated flowers, the corolla drops-off on third day, staminal tube after 10 days and calyx after 20 days and unpollinated flowers fall off on the third day. The ovary consecutively enlarges and burgeons into a fruit. The flowering of *P. pinnata* generally occurs through the year in some areas in the world. In Southeast Asia falling of leaves occurs in April and burgeoning new leaves from May and flower blossom in April to June. Its pod gets mature during March–May of following year and ripening of seeds occurs during February–May (**Table 1**).

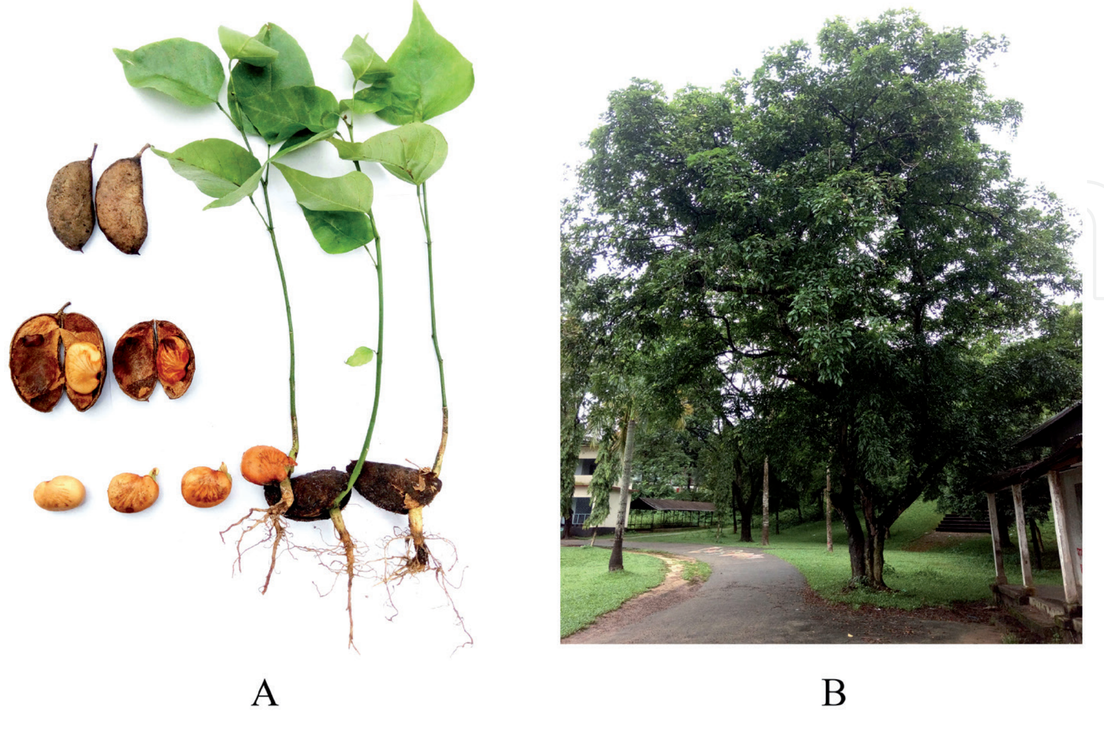

Figure 2.
P. pinnata *(A) pod, seed, and seedling, (B) whole* P. pinnata *tree. These photos of* P. pinnata *were taken from Murari Chand College campus, Sylhet, Bangladesh.*

Physiological stages	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seed ripening		■	■	■	■							
Pod ripening			■	■	■							
Flowering				■	■	■						
Fruiting												■
Falling of leaves				■								
Emergence of new leaves					■	■	■	■				
Source: Sangwan et al. [27].												

Table 1.
Growth pattern of P. pinnata.

For raising of extensive plantations and successful introduction of a species, identification of plus trees with good genetic qualities and selection of most feasible methods for the multiplication of huge number of plants are essential. Propagation of *Pongamia* is needed for many purposes. The planting time of *Pongamia* cannot be band together with its reproductive phase (flowering and fruiting) in different eco-geographic zones and in such case, year-round supply of planting material can be obtained by vegetative propagation. Further, *Pongamia* can be cultivated in large areas of non-arable and wastelands for domestic and commercial purposes. *Pongamia* can be successfully propagated through seeds, cuttings [28–30] and tissue culture [3] and the viability of seeds remain up to 1 year. *P. pinnata* is a cross pollinated species, and vegetative propagation is advantageous to such type of plant in producing true to type plants with shorter juvenile period leading to early productivity [25]. It can be propagated through semi hard and hard wood cuttings consist of 3–4 nodes. The stem cutting shows better rooting in terms of percentage response, average root number, and average root length which are collected during January than those are collected during October [14]. By grafting, long juvenile period can be avoided as well as good productivity can be assured owing to elite scions. In grafting of *Pongamia*, one-year old seedlings are used as rootstock and the scions can be collected from a superior genotype with the same dimensions as that of rootstock. The most successful grafting may be Wedge grafting, and it is done by using 3months old seedling as the stocks and 12–15 cm length semi hard wood scion [31]. *P. pinnata* can be easily multiplied by grafting than that of propagation by cuttings. Tissue culture techniques have the potential to reproduce large quantities of genetically identical propagules from a small amount of source tissue within short time. Generally, explants used for regeneration through tissue culture are buds, meristems, and leaves. Regeneration of explants may occur through organogenesis or somatic embryogenesis [32, 33]. However, success of tissue culture is mostly dependent on genetic constituents of individual tree under identical tissue culture conditions [3].

3. *P. pinnata* seed oil as biodiesel feedstock

3.1 Phytochemistry of *P. pinnata*

The chemical composition including major fatty acids of *P. pinnata* oil such as palmitic acid, stearic acid, linoleic acid, and eicosenoic acid indicate this oil could be good source for biodiesel feedstock [34]. The fatty acid compositions of *Pongamia* seed oil are described in **Table 2**. Some alkaloids such as demethoxy, gamaty, glabin, glabro saponin, kaempferol, kanjone, kanugin, karangin, neuroglobin, pinnatin, pongamol, pongapin, quercetin, saponin, b-sitosterol, and tannin were reported to found in *P. pinnata*. 31.0% charcoal, 36.69% pyroligneous acid, 4.3% acid, 3.4% ester, 1.9% acetone, 1.1% methanol, 9.0% tar, 4.4% pitches and losses, and 0.12m^3/kg gas were found by destructive distillation of the wood (dry weight basis). The nutrient level of *Pongamia* leaf, twig, and fruit are shown in **Table 3**.

Furthermore, the comparative composition of the predominant fatty acids in *Pongamia* and other biofuel sources such as corn, soybean, canola, palm, *Jatropha*, *Algae*, and tallow indicate the suitability of *Pongamia* oil as biodiesel feedstock (**Table 4**). These chemical properties of *Pongamia* establish it as potential biofuel crop. It has also been reported that the oil yield (liter/ha per annum) from *Pongamia* seed is higher than corn, soybean, canola, and *Jatropha*. From 4th to 5th year onward of plantation of *Pongamia* starts flowering and fruiting and producing seeds in 4th–7th years and a full-grown tree may give 9–90 kg seed which indicates it has the potential of yielding 900–9000 kg seed/ha (assuming 100 trees/ha). In India, 24–27.5% oil can be extracted in mills, 18–22% can be extracted by village crushers [15]. The yield of kernel ranges 8–24 kg per tree [12, 35] and contains about 28–34% oil with high percentage of polyunsaturated fatty acids [36]. In Australia per tree produces approximately 30 kg seeds per annum and containing up to 55% oil [3].

3.2 Physicochemical properties

The physicochemical properties of *Pongamia* seed oil have established it as a renewable source of biodiesel production. Oleic acid is responsible for low cloud

Fatty acids	Molecular formula	Composition (%)	Structure
Saturated fat	—	20.5	—
Monounsaturated fatty acid	—	46.0	—
Polyunsaturated fatty acid	—	33.4	—
Palmitic acid	$C_{16}H_{32}O_2$	3.7–11.3	$CH_3(CH_2)_{14}COOH$
Stearic acid	$C_{18}H_{36}O_2$	2.4–9.8	$CH_3(CH_2)_{16}COOH$
Oleic acid	$C_{18}H_{34}O_2$	44.5–71.3	$CH_3(CH_2)_{14}(CH{=}CH)COOH$
Linoleic acid	$C_{18}H_{32}O_2$	10.8–24.75	$CH_3(CH_2)_{12}(CH{=}CH)_2COOH$
Linolenic acid	$C_{18}H_{30}O_2$	2.9–6.3	$CH_3(CH_2)_{10}(CH{=}CH)_3COOH$
Eicosanoic acid	$C_{20}H_{40}O_2$	9.5–12.4	$CH_3(CH_2)_{18}COOH$
Behenic acid	$C_{22}H_{44}O_2$	4.2–5.3	$CH_3(CH_2)_{20}COOH$
Arachidic acid	$C_{20}H_{40}O_2$	0.8–4.7	$CH_3(CH_2)_{18}COOH$
Lignoceric acid	$C_{24}H_{48}O_2$	1.1–3.5	$CH_3(CH_2)_{22}COOH$
Myristic acid	$C_{14}H_{28}O_2$	0.23	$CH_3(CH_2)_{12}COOH$
Lauric acid	$C_{12}H_{24}O_2$	0.1	$CH_3(CH_2)_{10}COOH$
Capric acid	$C_{10}H_{20}O_2$	0.1	$CH_3(CH_2)_8COOH$
Unidentified	—	0.1–1.05	—

Source: Modified from Duke [15]; Ahmad et al. [37]; Karmee & Chadha [38]; Sarma et al. [15]; Kesari et al. [39].

Table 2.
Fatty acid composition of crude oil of Pongamia pinnata.

Parameter	Leaf and twig	Fruit (pod and seed)
Protein	—	17.4%
Fatty oil	—	27.5%
Nitrogen free extract	—	55.4%
Crude fiber	—	7.3%
Acid detergent fiber	40%	1.16%
Ash	—	2.4%
Tannin	—	2.32 g/100 g
Acid detergent lignin	—	6.67%
Trypsin	—	6.2 g/100 g
P	0.11, 0.14%	0.61%
Ca	1.54, 1.58%	0.65%
K	0.49, 0.62%	1.3%
Crude protein	18%	19.5 g/100 g
Neutral detergent fiber	62%	17.98%
N	0.71, 1.16%	5.1%
Moisture	—	19.0%
Starch	—	6.6%
Mucilage	—	13.5%
Na^+	—	0.8%

Source: Duke [15] and Singh [40].

Table 3.
Level of nutrients present in Pongamia *leaf and fruit.*

Plant	Oil yield (liter/ha per annum)	Percent oleic acid (C18:1)	Percent palmitic acid (C16:0)	Percent stearic acid (C18:0)	Reference
Corn	172	30.5–43	7–13	2.5–3	Dantas et al. [41]
Soybean	446	22–30.8	2.3–11	2.4–6	Hildebrand et al. [42]
Canola	1196	55–63	4–5	1–2	Moser [43]
Jatropha	1892	34.3–45.8	13.4–15.3	3.7–9.8	Becker and Makkar [44]; Islam et al. [45]
Palm oil	5950	38.2–43.5	41–47	3.7–5.6	Sarin et al. [46]
Algae[*]	59,000	1.7–14.3	3.7–40	0.6–6	Hu et al. [47]
Tallow	Not applicable	26–50	25–37	14–29	CanakciandSanli [48]
Pongamia	3600–4800	25.3–68.3	5.41–9.49	2.15–8	Biswas et al. [3]

[*]*The yield of* Algae *derived from smaller volume trails of multiple species.*

Table 4.
Major components of oil of several plants currently used as feedstock for biofuel production.

point so it is considered as important fatty acid in biodiesel production. Palmitic acid and stearic acid molecules have less mobility, thus increases the cloud point. As oxidation occurs in unsaturated C18 acids (linoleic acid and linolenic acid), these are less desirable (**Table 5**). These properties of *Pongamia* biodiesel ascertained as per ASTM (American Standards for Testing and Materials) standards which consist of viscosity (4.78 mm^2/s) that controls the characteristics of injection from diesel injector and for better performance the viscosity level should be minimized. The saponification number (187 mg/KOH) shows the relative length fatty acid chain; the iodine value (91I_2 100/g) indicates the total number of double bonds among the respective fatty acids; and the cetane number (41.7) gives an indication of ignition quality of the fuel. The flash point (144°C) is also an important property. Flash point is the temperature at which it ignites when exposed to a flame or spark. The flash point of biodiesel is higher than that of petroleum diesel, that's why it is safe for transport purpose. The lowest temperature at which oil can flow is known as pour point (−3°C for crude oil) and the cloud point (6°C) which is the temperature that will cause the dissolution of dissolved solids from the oil and indicates the possibility of use of biodiesel in temperature and cold climates. The pour point and cloud point of *Pongamia* biodiesel indicates the suitability of its use in tropical and some temperate regions. This non-edible *Pongamia* vegetables oil is the source of greenhouse gas neutral and environmentally acceptable biofuel. As an alternate to fossil fuel, *Pongamia* biodiesel can reduce CO_2, CO, HC, and NO emission by producing about 0.52 million tone of biodiesel per year from the unused lands [49].

Property	***Pongamia* crude oil**	***Pongamia* biodiesel**	**Diesel**
Color	Yellowish red	Amber yellow	White or slightly amber
Odor	Characteristic odd odor	—	—
Density	0.92 g/m^3	0.86 g/m^3	0.84 g/m^3
Kinematic viscosity @ 40°C	40.2 mm^2/s	4.78 mm^2/s	2.98 mm^2/s
Acid value	5.40 mg/KOH	0.42 mg/KOH	0.35 mg/KOH
Iodine value	87(I_2 100/g)	91(I_2 100/g)	—
Saponification value	184 (mg/KOH)	187 (mg/KOH)	—
Calorific value	8742 kcal/kg	3700 kcal/kg	4285 kcal/kg
Specific gravity	0.925	—	—
Unsaponifiable matter	2.9% w/w	—	—
Flash point	225°C	144°C	74°C
Fire point	230°C	—	—
Cloud point	3.5 °C	6 °C	−16°C
Pour point	−3 °C	—	—
Boiling point	316°C	—	—
Cetane number	42	41.7	49.0
Copper strip corrosion	No corrosion observed	—	—
Ash content	0.07%	0.005%	0.02%
Moisture	—	0.02%	0.02%
Carbon residue	1.51%	0.005%	0.01%

Source: Modified from Bobade and Khyade [39, 50].

Table 5.
Physico-chemical properties of P. pinnata *oil with diesel.*

Successful implementation of biofuels is depending on the supply of feedstock from non-food crops as well as the capacity to grow on marginal land that is not used for the cultivation of food crops [51]. From 15 years onward up to more 20 years, a *Pongamia* tree can produce 25–100 kg seed per year and after 30 years onward even up to 100 years, and each tree may produce 300–500 kg of seed per year with proper maintenance [52]. In this regard, *Pongamia* has the potentiality to supply significant amount of biofuel feedstock.

3.3 Biodiesel production

Biodiesel saves about 74% carbon dioxide emissions than conventional fuel [53]. Biodiesel from *P. pinnata* seed oil is the most useful product. However, *P. pinnata* seed oil could not considered to be suitable for direct use in the diesel engine due to high viscosity, free fatty acid content, and formation of gum during storage and combustion that causes thickening of lubricating oil and carbon deposits [54]. These drawbacks can be overcome by transesterification of bio-oil or straight vegetable oil that can produce biodiesel of nearly same properties as petroleum diesel. The transesterification process is the reaction of a triglyceride (with an alcohol to produce ester and glycerol). A triglyceride has a glycerine molecule as its base with three long chain fatty acids annexed. The characteristics of the fat are determined by the nature of the fatty acids subsumed to the glycerine which affects the characteristics of the biodiesel. In production of biodiesel, vegetable oil in the form of triglycerides reacts with small chain alcohol (methanol, ethanol, propanol, etc.) in the presence of homogeneous catalyst such as base (KOH, NaOH) or acid (HCl, H_2SO_4, H_3PO_4). The process is also called alcoholysis. When methanol is used, it is called methanolysis and esters that produced in methanolysis are called fatty acid methyl esters (FAMEs) and in case of ethanol, the process is termed as ethanolysis and the esters produced in this process are called fatty acid ethyl esters (FAEEs) [55]. The transesterification is a reversible reaction, so alcohol must be added in excess to ensure the reaction in the right direction. 80% methyl ester and 20% glycerin can be produced as by product through transesterification at low temperature and pressure [39]. The conditions for optimal reaction such as concentration of catalyst, molar ratio of alcohol/oil, and temperature have been investigated and optimized by Meher et al. [56]. Furthermore, Azam et al. [10] have reported that the FAMEs of *Pongamia* seed oil is most suitable as it meets the standard specifications of biodiesel. The reaction during transesterification can be described as below [57] (**Figure 3**).

The transesterification process for biodiesel production from *Pongamia* was described by Mahanta et al. [57]. Briefly, a known amount of oil was preheated to remove the moisture from the oil and then the oil was transferred to a reaction chamber in a hot water bath where 65–70°C temperature should be maintained. Based on the acid value of the oil, calculated amount of KOH and methanol were added and the mixture was stirred for 10–15 minutes for complete mixing. The temperature of the reaction should be maintained at 60°C. The reaction was considered to be completed when a clear separation was observed between oil and glycerol. After removing from the water bath, the mixture was kept for 7–8 hours for complete separation. After cooling, two layers were differentiated: the upper layer is methyl ester (biodiesel) with a little amount of KOH, soap, and other impurities and the lower layer is glycerol. The biodiesel was collected by drain out of the upper layer, and remaining KOH, soap, and impurities were removed by using a separating funnel. Twenty-five percent by volume of impure methyl ester with warm distilled water is taken in a separating funnel. The impurities, KOH, and soap were solubilized in water and settled at the bottom of the funnel that can be drained

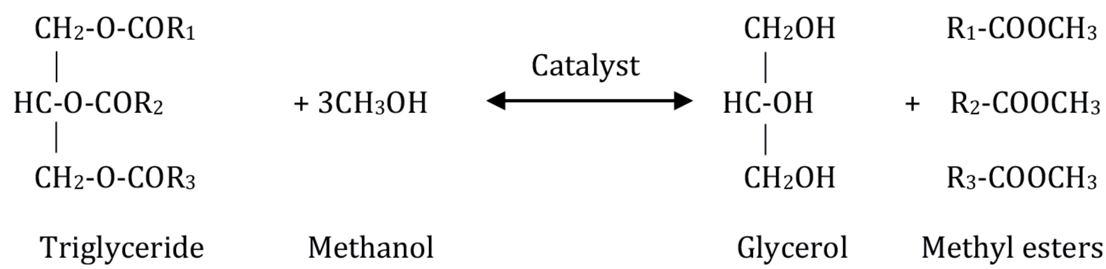

Figure 3.
Transesterification reaction for biodiesel production.

out easily. This washing was repeated until the pH of the separated water reaches at level of 7–8. Finally, amber yellow color biodiesel was obtained from *P. pinnata* seed oil [57]. Transesterification of 100 L of *P. pinnata* crude oil can produce about 85 L of biodiesel and 15 L of glycerin as byproduct [58]. The Koroch tree has long life up 100 years. Its seed contains 25–35% non-edible oil extracted by mechanical press. It is also reported that 1 L of crude oil can be produced from about 4 kg of *P. pinnata* seed which ultimately can produce about 896 mL of biodiesel [59]. After oil extraction, oil cake, a by-product could be used as fertilizer or solid fuel [52].

4. Other uses and benefits

4.1 Biogas production and bio-fertilizer

The biomass waste from biofuel crops like *Jatropha* can be utilized for the production of biogas and bio-fertilizer [60]. Gunaseelan et al. [61] studied the potential of biogas (CH_4) production from NaOH treated and untreated *P. pinnata* biomass waste. The results indicated that maximum amount of CH_4 was produced from untreated seeds, whereas lower amount of CH_4 was produced from withered yellow leaves of *P. pinnata*. The yield of CH_4 from fiber rich leaves and pod husk was increased by 15–22% when treated with NaOH [61]. The deoiled cake of *Pongamia* cannot be used for animal feeding or agricultural farming directly due to its toxic properties. The generation of biogas by anaerobic digestion of oilseed cakes would be best solution for its efficient utilization which provides a better quality renewable gaseous fuel (biogas) than cattle dung to generate biogas. However, the co-digestion of cattle dung with *Pongamia* seed cakes accelerate the digestion process. The C-N ratio of *P. pinnata* oil seeds cake was found 8.7, and the pH value ranges between 4.8–9.4 depending on percentage of cattle dung, cake, and water dilution ratio. Total biogas generation potential from *P. pinnata* cakes has been estimated as 377 million cubic meter from 0.145 million tone of *P. pinnata* oil cakes [62]. Along with fuel, anaerobic digestion gives good manorial value effluent for organic farming. *P. pinnata* oil cake contains higher amount of N, P, K (4%, 1%, 1%) than vermicompost [63].

4.2 Firewood and briquette

The wood of *P. pinnata* is considered as low quality timber due to its softness, tendency to split during sowing, and vulnerability to insect attack [16]. Traditionally, *P. pinnata* wood is used as fuel in rural areas in India, Bangladesh, and other neighboring regions. It has no distinct heartwood and varies from white to yellowish gray color with a calorific value of 19.32 MJ/kg. The ash produced from burning wood is used for dyeing [64]. Briquettes can be produced from shell and deoiled cake of *Pongamia*. The harvested pods are decorticated to separate the shells, and the shells are pulverized to prepare the materials for briquette preparation. The pulverized product is blended with other biomass to increase calorific value and compressed with a piston press to produce the *Pongamia* briquette. Briquettes that produced by following typical method result in a high heating value of 4000 kcal/kg [63].

4.3 Medicinal and pharmaceutical use

P. pinnata has been used as folk medicine or crude drug from pre-modern period. Recently, many pharmacological studies have been carried out on *P. pinnata*. Ethanolic extract of *P. pinnata* leaf was reported to have anti-inflammatory activity against various stages (acute, sub-acute, and chronic) of inflammation and also anti-pyretic function against Brewer's yeast-induced pyrexia [65]. Shing and Pandey [66] showed that petroleum ether extraction of seeds of *P. pinnata* have powerful acute anti-inflammatory activity, whereas the aqueous suspension showed pro-inflammatory activity. It shows anti-plasmodial activity against *Plasmodium falciparum* [67]. The leaf extract of Koroch shows defensive characteristics against blood ammonia and urea levels in ammonium chlorides induced hyperammonemia [68]. Shoba and Thomas [69] reported on the protective effect of *P. pinnata* in inhibiting castor oil induced diarrhea. Brijesh et al. [70] found that the crude extract of dried leaves of *P. pinnata* had a potential effect against the production of cholera toxin and enteroinvasive bacterial strains that cause diarrhea. Antihyperglycaemic and Antilipidperoxidative effects of ethanolic extract of *Pongamia* flowers in alloxan induced diabetic rats were evaluated by Punitha and Manoharan [71]. Rameshthangam and Ramasamy [72] noticed the antiviral activity of bis (2-methylhepty1) phthalate isolated from *Pongamia* leaves against White Spot Syndrome Virus of *Penaeus mondon fabricius.* Oral injection of ethanolic extract and purified compound from the leaves of *Pongamia pinnata* has increased the survival of WSSV infected *Penaeus mondon*. The fruits and leaves extract of *Pongamia pinnata* possess antifilarial potential of on cattle filarial parasite which was investigated by Uddin et al. [73].

4.4 Bio-pesticide

Oil extracted from seeds of *Pongamia* used in agriculture as it functions against the insect pests. The main active ingredient of *Pongamia* oil is Karanjin which used as acaricide and insecticide. Karanjin also possess nitrification inhibitory properties. Application of the insecticide based on *Pongamia* oil causes high larval mortality of *Plutella xylostella* and significantly reduces the damage caused by feeding to crops. The product formulation based on the combination of *P. pinnata* and *Thymus vulgaris* or *Foeniculum vulgare* essential oils can be recommended against *Plutella xylostella* larvae for protection of cabbage crops [74]. Mechanical extraction of *Pongamia* seeds produces oil seeds cakes as byproducts. These seed cakes are generally toxic but the toxicity can be minimized by using them as bio-pesticides. Further this oil cake can be used as low cost substrates for the growth of the fungus *Paecilomyces* playing an important role in controlling nematodes. The aqueous and methanolic extracts and the crude active components of the cake cause significant termite mortality [75].

4.5 Nitrogen fixation and nodulation

P. pinnata has the quality to fix atmospheric nitrogen. The nodulation of most legumes occurs effectively with one or few specific species of *Rhizobia.* However, nodulation process of *Pongamia* has been found to be quite promiscuous, which make symbiosis with different species of both *Bradyrhizobium* and *Rhizobium* [76–78]. The capacity of *Pongamia* to fix nitrogen with these species of *Rhizobia* has not been reported, and the establishment of superior inoculants was not possible [78]. Nodulation in legume can either be determinate with a spherical morphology due to lack of persistent meristems or indeterminate where holding of meristems produces more cylindrical nodules. *Pongamia* nodules have been noticed to be determinate in nature [1, 79] but older *Pongamia* trees will indicate a combination of spherical and coralloid nodules. Therefore, as a tree, *Pongamia* represents both qualitatively and quantitatively major features found in other better-characterized annual legume crops, such as soybean and pea (*Pisum sativum* L.).

Besides above discussed uses different part or as whole *Pongamia* also be used for shade and shelter, controlling soil erosion, soil reclamation, fish poison, apiculture, fiber, tannin or dyestuff, and ornamentals.

5. Current status and future prospects and challenges

Pongamia is versatile plant, and it is more valued for its biodiesel properties but its production is not satisfactory level. In Bangladesh, commercial cultivation and production of biodiesel and bio-ethanol from *P. pinnata* has not started yet [16]. *Pongamia* and other fuel crops are not planted commercially, and no mass plantation program has been taken yet. *Pongamia* is planted in lower areas of Sunamganj district of Bangladesh for windbreak and to control soil erosion. In Bangladesh, Koroch was naturally grown at Ratargul Swamp Forest, Gowainghat, Sylhet. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Andhra Prdesh, India is supporting innovative research on the *Pongamia* "journey from Forest to Micro-enterprise" to ameliorate rural liflode and empowerment. The purpose of this organization is to exonerate the degraded lands and conserve the environments, to assess and elevate sustainable crop management practices and to assess the enhancement of income of self-helped groups by planting *Pongamia*. There is also another target to value addition of its byproducts after extraction of oil. There is about 28 institution in India, and they are working for undertaking joint research on some issues such as marking of prime planting materials, seed resource assessment, collection and storage, phonological and chemical analysis for characterization, improvement of trees to get quality and reliable seed source, multi-location trials of superior planting materials, and agro-forestry models for evolving good intercropping system of tree borne oilseeds [54]. It has been cultivated outside its native range in South-eastern Queensland, Australia.

To fulfill the future demands for biodiesel and to increase the production of *Pongamia*, mass plantation program should be taken through commercially or social afforestation by the Government, NGOs, and by Private Public Partnership. Local communities who participate in this program may not be much interested until they know the value of plant genetic resources. The involvement of the local people will be assured through a program to aware them by display of charts and posters arranged in the local language and also by field demonstration to present the economic viability and feasibility of cultivation as an alternative choice on degraded lands and community wastelands. Therefore, value addition to a plant, thereby emphasizing on the livings of the local communities, would be an efficient mode for propagation and management in *Pongamia*. Field-level laborers are engaged in extension activities of *Pongamia* cultivation should be trained on the different aspects of *Pongamia* plant cultivation such as value of superior planting elements, collection of elite germplasm, developing nursery, plantation establishment, and post cultivation care. Clonal cuttings of the elite materials or candidate plus tree can be supplied to enhance the plantation of *Pongamia* on more marginal and wastelands. Different improved plant breeding methods should be used to develop of early bearing *Pongamia* varieties so that it shortens the growth period and increases oil content with desirable oil properties especially monounsaturated fatty acid from the point of view of using it as biofuel. Again to produce *Pongamia* seeds all the year round, selection of day neutral verities is necessary. So development of high yield *Pongamia* varieties produced in the "off season" could also be attempted for strategies toward development of dwarf high-yielding varieties that can minimize the management cost also be possible. Further techniques for development of location-specific genotypes that are resistant to adverse growing condition such as salinity, draught, alkalinity, and water logging can be considered as future research so as to enhance the range of growth and cultivation of *Pongamia*.

6. Conclusion

Pongamia is an underutilized species but it has great potential for use in production of biodiesel and in pharmaceuticals. Furthermore, wasteland can be effectively used for cultivation and subsequent agronomic or silvicultural practices and also helps in bucolic development and poverty alleviation through development of employment opportunities. To increase the production of *Pongamia* standardization of the vegetative propagation techniques, large-scale production of genetically superior saplings throughout the year, appropriate planting models for different agro-ecological zones and land uses and post planting care are of prime importance. Thus, the future success of *Pongamia* as a sustainable source of feedstock for the biofuel industry is dependent on an extensive knowledge of the genetics, physiology, and propagation of this legume. Moreover, research activities should be targeted to ameliorate the physic-chemical properties and plant growth as it relates to oil biosynthesis.

Acknowledgements

The author acknowledges the support of the Ministry of Science and Technology (NST), Government of Bangladesh for providing all research inputs and cost of the project. The authors would like to thank NST authority for their support.

Conflict of interest

There is no conflict of interest regarding the publication of this chapter.

Author details

Abul Kalam Mohammad Aminul Islam[1*], Swapan Chakrabarty[1], Zahira Yaakob[2], Mohammad Ahiduzzaman[3] and Abul Kalam Mohammad Mominul Islam[4]

1 Department of Genetics and Plant Breeding, Faculty of Agriculture, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh

2 Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Selangor, Malaysia

3 Department of Agro-Processing, Faculty of Agriculture, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh

4 Department of Agronomy, Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh, Bangladesh

*Address all correspondence to: aminulgp@bsmrau.edu.bd

References

[1] Scott PT, Pregelj L, Chen N, Hadler JS, Djordjevic MA, Gresshoff PM. *Pongamia pinnata*: An untapped resource for the biofuels industry of the future. Bioenergy Research. 2008;**1**(1):2-11

[2] Orwa C, Mutua A, Kindt R, Jamnadass R, Simons A. Agroforestree Database: A Tree Species Reference and Selection Guide Version 4.0. Nairobi, KE: World Agroforestry Centre ICRAF; 2009

[3] Biswas B, Kazakoff SH, Jiang Q, Samuel S, Gresshoff PM, Scott PT. Genetic and genomic analysis of the tree legume as a feedstock for biofuels. Plant Genome. 2013;**6**(3):1-15

[4] Bottoms T, Lane M. Bama country - aboriginal homelands. In: McDonald GG, Lane MM, editors. Securing the Wet Tropics. Leichardt, NSW: Federation Press; 2000. pp. 32-47

[5] Cribb AB, Cribb JW. Useful Wild Plants in Australia. Sydney: Collins; 1981

[6] Chopade V, Tankar A, Pande V, Tekade A, Gowekar N, Bhandari S, et al. *Pongamia pinnata*: Phytochemical constituents, traditional uses and pharmacological properties: A review. International Journal of Green Pharmacy. 2008;**2**(2):72

[7] Uddin MB, Mukul SA, Khan MASA, Hossain MK. Seedling response of three agroforestry tree species to phosphorous fertilizer application in Bangladesh: Growth and nodulation capabilities. Journal of Forestry Research. 2009;**20**(1):45-48

[8] Shereena KM, Thangaraj T. Biodiesel: An alternative fuel produced from vegetable oils by transesterification. Electronic Journal of Biology. 2009;**5**(3):67-74

[9] Barnwal BK, Sharma MP. Prospects of biodiesel production from vegetable oils in India. Renewable and Sustainable Energy Reviews. 2005;**9**:363-378

[10] Azam MM, Waris A, Nahar NM. Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India. Biomass and Bioenergy. 2005;**29**(4):293-302

[11] Nagaraj G, Mukta N. Seed composition and fatty acid profile of some tree borne oilseeds. Journal of Oilseeds Research. 2004;**21**(1): 117-120

[12] Kesari V, Krishnamachari A, Rangan L. Systematic characterisation and seed oil analysis in candidate plus trees of biodiesel plant, *Pongamia pinnata*. Annals of Applied Biology. 2008;**152**(3):397-404

[13] Mukta N, Sreevalli Y. Propagation techniques, evaluation and improvement of the biodiesel plant, *Pongamia pinnata* (L.) Pierre—A review. Industrial Crops and Products. 2010;**31**(1):1-12

[14] Kesari V, Krishnamachari A, Rangan L. Effect of auxins on adventitious rooting from stem cuttings of candidate plus tree *Pongamia pinnata* (L.), a potential biodiesel plant. Trees - Structure and Function. 2009;**23**(3):597-604

[15] Duke JA. Handbook of Energy Crops, unpublished. 1983. Available from: https://www.hort.purdue.edu/newcrop/duke_energy/Pongamia_pinnata.html [Accessed: 03 June 2017]

[16] Daniel JN. *Pongamia pinnata*-a nitrogen fixing tree for oilseed. In: NFT Highlights. Arkansas, USA: Winrock International; 1997

[17] Gilman EF, Watson DG. *Pongamia pinnata* Pongam. In: Fact Sheet ST-498. A series of the Environmental Horticulture Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences. Gainesville, FL, USA: University of Florida; 1994

[18] Misra CM, Singh SL. Ecological evaluation of certain leguminous trees for agroforestry. Nitrogen Fixing Tree Research Reports. 1987;**5**:5

[19] Tomar OS, Gupta RK. Performance of some forest tree species in saline soils under shallow and saline water-table conditions. Plant and Soil. 1985;**87**(3):329-335

[20] Troup RS, Joshi HB. Troup's Silviculture of Indian Trees, Vol. IV Leguminosae. Dehra Dun, India: Forest Research Institute and Colleges; 1983. pp. 33-38

[21] CAB International. Forestry Compendium Global Module. Wallingford, UK: CAB International; 2000

[22] Dwivedi G, Jain S, Sharma MP. *Pongamia* as a source of biodiesel in India. Smart Grids and Renewables. 2011;**2**:184-189

[23] Allen ON, Allen EK. The Leguminosae. Madison, Wisconsin, USA: The University of Wisconsin Press; 1981. p. 812

[24] Daniel JN, Hegde NG. Tree-borne oilseeds in agroforestry. In: Proceedings of the National Seminar on Changing Global Vegetable Oils Scenario: Issues and Challenges before India. Hyderabad, India: Indian Society of Oil seeds Research Publication; 2007. pp. 263-276

[25] Raju AS, Rao SP. Explosive pollen release and pollination as a function of nectar-feeding activity of certain bees in the biodiesel plant, *Pongamia pinnata* (L.) Pierre (Fabaceae). Current Science (Bangalore). 2006;**90**(7):960

[26] Galen C, Zimmer KA, Newport ME. Pollination in floral scent morphs of *Polemonium viscosum*: A mechanism for disruptive selection on flower size. Evolution. 1987;**41**(3):599-606

[27] Sangwan S, Rao DV, Sharma RA. A review on *Pongamia pinnata* (L.) Pierre: A great versatile leguminous plant. Nature and Science. 2010;**8**(11):130-139

[28] Handa AK, Nandini D. An alternative source of biofuel, seed germination trials of *Pongamia pinnata*. International Journal of Forest Usufructs Management. 2005;**6**(2):75-80

[29] Singh KP, Dhakre G, Chauhan SVS. Effect of mechanical and chemical treatments on seed germination in *Pongamia glabra L*. Seed Research. 2005;**33**(2):169

[30] Kesari V, Das A, Rangan L. Effect of genotype and auxin treatments on rooting response in stem cuttings of CPTs of *Pongamia pinnata*, a potential biodiesel legume crop. Current Science. 2010;**98**(9):1234-1237

[31] Karoshi VR, Hegde GV. Vegetative propagation of *Pongamia pinnata* (L) Pierre: Hitherto a neglected species. Indian Forester. 2002;**128**(3):348-350

[32] Biswas B, Scott PT, Gresshoff PM. Tree legumes as feedstock for sustainable biofuel production: Opportunities and challenges. Journal of Plant Physiology. 2011;**168**(16):1877-1884

[33] Sujatha K, Panda BM, Hazra S. De novo organogenesis and plant regeneration in *Pongamia pinnata*, oil producing tree legume. Trees. 2008;**22**(5):711-716

[34] Bobade SN, Khyade VB. Detail study on the properties of *Pongamia pinnata* (Karanja) for the production of biofuel. Research Journal of Chemical Sciences. 2012;**2**(7):16-20

[35] Bringi NV. Non-Traditional Oilseeds and Oils in India. New Delhi: Oxford and IBH Pub. Co. Pvt. Ltd; 1987. pp. 143-166

[36] Sarma AK, Konwer D, Bordoloi PK. A comprehensive analysis of fuel properties of biodiesel from Koroch seed oil. Energy & Fuels. 2005;**19**(2):656-657

[37] Ahmad S, Ashraf SM, Naqvi F, Yadav S, Hasnat A. A polyesteramide from *Pongamia glabra* oil for biologically safe anticorrosive coating. Progress in Organic Coatings. 2003;**47**(2):95-102

[38] Karmee SK, Chadha A. Preparation of biodiesel from crude oil of *Pongamia pinnata*. Bioresource Technology. 2005;**96**(13):1425-1429

[39] Kesari V, Das A, Rangan L. Physico-chemical characterization and antimicrobial activity from seed oil of *Pongamia pinnata*, a potential biofuel crop. Biomass and Bioenergy. 2010;**34**(1):108-115

[40] Singh RV. Fodder Trees of India. New Delhi, India: Oxford and IBH Co.; 1982

[41] Dantas M, Conceição M, Fernandes V Jr, Santos N, Rosenhaim R, Marques A, et al. Thermal and kinetic study of corn biodiesel obtained by the methanol and ethanol routes. Journal of Thermal Analysis and Calorimetry. 2007;**87**(3):835-839

[42] Hildebrand DF, Li R, Hatanaka T. Genomics of soybean oil traits. In: Genetics and Genomics of Soybean. New York: Springer; 2008. pp. 185-209

[43] Moser BR. Biodiesel production, properties, and feedstocks. In Vitro Cellular & Developmental Biology – Plant. 2009;**45**(3):229-266

[44] Becker K, Makkar HPS. *Jatropha curcas*: A potential source for tomorrow's oil and biodiesel. Lipid Technology. 2008;**20**(5):104-107

[45] Islam AKMA, Primandari SRP, Anuar N, Yaakob Z, Osman M. Preparation of biodiesel from *Jatropha* hybrid seed oil through two step transesterification. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2015;**37**(14):1550-1559

[46] Sarin R, Sharma M, Sinharay S, Malhotra RK. Jatropha–palm biodiesel blends: An optimum mix for Asia. Fuel. 2007;**86**(10):1365-1371

[47] Hu Q, Sommerfeld M, Jarvis E, Ghirardi M, Posewitz M, Seibert M, et al. Microalgal triacylglycerols as feedstocks for biofuel production: Perspectives and advances. The Plant Journal. 2008;**54**(4):621-639

[48] Canakci M, Sanli H. Biodiesel production from various feed stocks and their effects on the fuel properties. Journal of Industrial Microbiology & Biotechnology. 2008;**35**(5):431-441

[49] Halder PK, Paul N, Beg MRA. Prospect of *Pongamia pinnata* (Karanja) in Bangladesh: A sustainable source of liquid fuel. Journal of Renewable Energy. 2014:1-12. Article ID 647324. DOI: 10.1155/2014/647324

[50] Bobade SN, Khyade VB. Preparation of methyl ester (biodiesel) from karanja (*Pongamia pinnata*) oil. Research Journal of Chemical Sciences. 2012;**2**(8):43-50

[51] Hill J, Nelson E, Tilman D, Polasky S, Tiffany D. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels.

Proceedings of the National Academy of Sciences. 2006;**103**(30):11206-11210

[52] Rahman MM, Ahiduzzaman M, Islam AS, Blanchard R. Karoch (*Pongamia pinnata*)-An alternative source of biofuel in Bangladesh. In: 2014 3rd International Conference on the Developments in Renewable Energy Technology (ICDRET). IEEE; 2014. pp. 1-6

[53] US-DOE. Alternative Fuel Data Center, Energy Efficiency and Renewable Energy. 2017. Available from: https://www.afdc.energy.gov/fuels/biodiesel_benefits.html [Accessed: 25 July 2017]

[54] Kesari V, Rangan L. Development of *Pongamia pinnata* as an alternative biofuel crop-current status and scope of plantations in India. Journal of Crop Science and Biotechnology. 2010;**13**(3):127-137

[55] Roces SA, Tan R, Da Cruz FJT, Gong SC. Methanolysis of *Jatropha* oil using conventional heating. ASEAN Journal of Chemical Engineering. 2011;**11**(1):41-46

[56] Meher LC, Dharmagadda VS, Naik SN. Optimization of alkali-catalyzed transesterification of *Pongamia pinnata* oil for production of biodiesel. Bioresource Technology. 2006;**97**(12):1392-1397

[57] Mahanta P, Sarmah JK, Kalita P, Shrivastava A. Parametric study on transesterification process for biodiesel production from *Pongamia pinnata* and *Jatropha curcas* oil. International Energy Journal. 2008;**9**(1):41-46

[58] Chandrashekar LA, Mahesh NS, Gowda B, Hall W. Life cycle assessment of biodiesel production from pongamia oil in rural Karnataka. Agricultural Engineering International: CIGR Journal. 2012;**14**(3):67-77

[59] Patil VK, Bhandare P, Kulkarni PB, Naik GR. Progeny evaluation of *Jatropha curcas* and *Pongamia pinnata* with comparison to bioproductivity and biodiesel parameters. Journal of Forestry Research. 2015;**26**(1):137-142

[60] Primandari SRP, Islam AKMA, Yaakob Z, Chakrabarty S. *Jatropha curcas* L. biomass waste and its utilization. In: Advances in Biofuels and Bioenergy. London, UK: InTech Open; 2018. p. 273

[61] Gunaseelan VN. Biogas production from *Pongamia* biomass wastes and a model to estimate biodegradability from their composition. Waste Management & Research. 2014;**32**(2):131-139

[62] Chandra R, Vijay VK, Subbarao PM. A study on biogas generation from non-edible oil seed cakes: Potential and prospects in India. In: The 2nd Joint International Conference on Sustainable Energy and Environment. 2006. pp. 21-23

[63] Venkatesan R, Dampuri K, Challoo R, Shankar A. Green power production from Pinnata. In: World Environmental and Water Resources Congress. Sacramento, California, USA: American Society of Civil Engineers; 2017. pp. 228-240

[64] Moniruzzaman M, Yaakob Z, Shahinuzzaman M, Khatun R, Islam AKMA. Jatropha Biofuel Industry: The Challenges. USA: Publish by INTECH publisher; 2016

[65] Srinivasan K, Muruganandan S, Lal J, Chandra S, Tandan SK, Prakash VR. Evaluation of anti-inflammatory activity of *Pongamia pinnata* leaves in rats. Journal of Ethnopharmacology. 2001;**78**(2):151-157

[66] Singh RK, Pandey BL. Anti-inflammatory potential of *Pongamia pinnata* root extracts in experimentally

induced inflammation in rats. Journal of Applied Biomedicine. 1996;**4**:21-24

[67] Simonsen HT, Nordskjold JB, Smitt UW, Nyman U, Palpu P, Joshi P, et al. *In vitro* screening of Indian medicinal plants for antiplasmodial activity. Journal of Ethnopharmacology. 2001;**74**(2):195-204

[68] Essa MM, Subramanian P, Suthakar G, Manivasagam T, Dakshayani KB. Protective influence of *Pongamia pinnata* (Karanja) on blood ammonia and urea levels in ammonium chloride-induced hyperammonemia. Journal of Applied Biomedicine. 2005;**3**(3):133-138

[69] Shoba FG, Thomas M. Study of antidiarrheal activity of four medicinal plants in castor-oil induced diarrhoea. Journal of Ethnopharmacology. 2001;**76**(1):73-76

[70] Brijesh S, Daswani PG, Tetali P, Rojatkar SR, Antia NH, Birdi TJ. Studies on *Pongamia pinnata* (L.) Pierre leaves: Understanding the mechanism (s) of action in infectious diarrhea. Journal of Zhejiang University. Science. B. 2006;**7**(8):665-674

[71] Punitha R, Manoharan S. Antihyperglycemic and antilipidperoxidative effects of *Pongamia pinnata* (Linn.) Pierre flowers in alloxan induced diabetic rats. Journal of Ethnopharmacology. 2006;**105**(1):39-46

[72] Rameshthangam P, Ramasamy P. Antiviral activity of bis (2-methylheptyl) phthalate isolated from *Pongamia pinnata* leaves against white spot syndrome virus of *Penaeus mondon fabricius*. Virus Research. 2007;**126**(1):38-44

[73] Uddin Q, Parveen N, Khan NU, Singhal KC. Antifilarial potential of the fruits and leaves extracts of *Pongamia pinnata* on cattle filarial parasite Setaria cervi. Phytotherapy Research. 2003;**17**(9):1104-1107

[74] Pavela R. Efficacy of three newly developed botanical insecticides based on pongam oil against *Plutella xylostella* L. larvae. Journal of Biopesticides. 2012;**5**(1):62-70

[75] Sharma S, Verma M, Sharma A. Utilization of non- edible oil seed cakes as substrate for growth of *Paecilomyces lilacinus* and as biopesticide against termites. Waste and Biomass Valorization. 2013;**4**(2):325-330

[76] Arpiwi NL, Yan G, Barbour EL, Plummer JA. Genetic diversity, seed traits and salinity tolerance of *Millettia pinnata* (L.) Panigrahi, a biodiesel tree. Genetic Resources and Crop Evolution. 2013;**60**(2):677-692

[77] Kesari V, Ramesh AM, Rangan L. *Rhizobium pongamiae* sp. nov. from root nodules of *Pongamia pinnata*. BioMed Research International. 2013:1-9. Article ID 165198. DOI: 10.1155/2013/165198

[78] Rasul A, Amalraj E, Praveen Kumar G, Grover M, Venkateswarlu B. Characterization of rhizobial isolates modulating *Millettia pinnata* in India. FEMS Microbiology Letters. 2012;**336**(2):148-158

[79] Kazakoff SH, Gresshoff PM, Scott PT. *Pongamia pinnata*, a Sustainable Feedstock for Biodiesel Production. London: Energy crops. Royal Society of Chemistry; 2011. pp. 233-254