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Review article

Pongamia (*Pongamia pinnata*): a sustainable alternative for Biofuel Production and Land Restoration in Indonesia

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Abstract: Indonesia has a large area of degraded land, i.e. 30 million ha, which could potentially be utilized for biofuel plantations. The leguminous tree pongamia (*Pongamia pinnata* syn. *Milettia pinnata*) could be utilized to produce biofuel while restoring degraded land. Here, we explore the potential of pongamia as a source of biofuel and for restoring degraded land in Indonesia. Pongamia occurs across Indonesia, in Sumatra, Java, Bali, West Nusa Tenggara and Maluku. It grows to a height of 15–20 m and can grow in a range of environmental conditions. Its seeds can generate up to 40% crude oil by weight. It can help to restore degraded land and improve soil properties. Pongamia also provides wood, fodder, medicine, fertilizer and biogas. Therefore, as a multipurpose species, pongamia holds great potential to combat Indonesia's energy crisis and to restore much of the degraded land.

Keywords: Indonesia, biofuel, land restoration, pongamia

1. Introduction

An ever-increasing energy demand has raised the importance of new and renewable sources of energy [1, 2]. Petroleum fuel is the primary source of energy used by communities in Indonesia to run their cars, and many other types of vehicles that need petroleum fuel to operated, such as boats and agricultural tractors [1]. In recent years, Indonesia has switched from being a petroleum-exporting to a petroleum-importing country and, by 2030, its own natural reserves will be depleted and unable to support demand [2]. This realization has highlighted the need to find and develop alternative sources of energy. Biofuel is considered to be an important alternative source of energy [2]. Therefore, the Indonesian government's national energy policy supports new and renewable energy, which could provide up to 23% of national energy needs by 2025 and 31% by 2050 [3].

Globally, at present, biofuel is mostly obtained from oil palm, coconut, cassava, corn, sorghum and other edible food plants. Non-edible energy sources, e.g. jatropha (*Jatropha curcas*), have also been introduced, but require fertile land to achieve high yields and the resulting competition with food and cash crops limits its overall production prospects [4]. Therefore, there is an urgent need to

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identify non-edible plant species that can be used as an energy source and can grow on abandoned lands, i.e. marginal or degraded lands. Pongamia (*Pongamia pinnata* syn. *Milettia pinnata*) is such a species: its seeds are valued for their biofuel properties and it can grow in a marginal land [5].

Indonesia has a large area of degraded and marginal lands. The Ministry of Environment and Forestry has identified 30 million ha of degraded lands [6]. Several government agencies in Indonesia have land restoration targets, including the Peatland Restoration Agency (*Badan Restorasi Gambut*, BRG) that aims to restore more than 2 million ha of degraded peatland in Riau, Jambi, South Sumatra, West Kalimantan, Central Kalimantan, South Kalimantan and Papua [7]. Restoring some of these lands using suitable biofuel species (e.g. pongamia) can provide an opportunity to enhance ecosystem services [8,9] and support local economies [10–12]. Pongamia grows naturally in Indonesia and can survive on degraded land. This review provides information on its distribution, growth, yields, biofuel potential and land restoration capacity to corroborate scientific understanding. It provides a valuable resource that practitioners and policymakers can use in planning projects [13–15].

2. Materials and Methods

This study is based on a robust and thorough literature review of both the peer-reviewed and grey literature. Using selected key words and phrases (Table 1), relevant literatures were gathered from the internet using scientific research search sites, i.e. Google Scholar, Mendeley, Scopus and Web of science. The review was conducted from January to September 2018. At the outset of the review, the inclusion criteria (Table 1) were necessarily rudimentary to gather targeted information of pongamia. Therefore, we have conducted a quick review of the abstracts and contents of the retrieved literatures to evaluate their relevance to be included for extensive review for our study. While we did not expect literature that can report all of the relevant information, we have developed an Excel database to capture any relevant information found during the literature screening process, to enhance consistency and effective analysis.

Table 1. Search sites, key words and inclusion criteria to generate targeted information from literature review used in this study

Search sites	Key words and search phrases	Inclusion criteria
Google Scholar. Mendeley. Scopus. Web of science.	'pongamia', 'bioenergy', 'biofuel', 'jet fuel', 'pongamia and bioenergy', 'pongamia and biofuel', 'pongamia oil', 'bioenergy and Indonesia', 'biofuel and Indonesia', 'pongamia, bioenergy and Indonesia', 'pongamia, biofuel and Indonesia', 'pongamia and land restoration', 'pongamia, land restoration and Indonesia', 'pongamia and nitrogen', 'pongamia, land restoration and nitrogen', 'pongamia benefit', 'potential of pongamia', 'pongamia wood', 'pongamia medicine', 'pongamia agroforestry', 'pongamia based agroforestry', 'pongamia landscape'.	Evidence based information of pongamia, i.e. distribution, growth, yields, biofuel potential, land restoration capacity.

The relevant information was carefully compiled point-by-point, and scientific interpretation was made by using the narrative qualitative and narrative comparative analysis method. The analysis process is designed to scrutinize relevant concepts from textual data in a transparent subjective way.

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Careful attention was paid for a more discursive interpretation and to represent a view of reality through a process of decontextualization and recontextualization with appropriate scientific order as presented in section 3 below.

3. Results and Discussion

3.1. Potential of pongamia as a biofuel species

3.1.1. Distribution

Pongamia is a humid and sub-tropical plant. It grows in a wide range of agro-climatic conditions. Although native to India, China, Pakistan, Sri Lanka, Vietnam, Malaysia, Indonesia, Japan, Fiji and Australia, it has gradually been introduced to Egypt, United States, Puerto Rico and many African countries. It is commonly called Indian beech, Karum tree (English); pongam (Gujarat); dalkaramch (Tamil Nadu); karanj, karanja, kanji (Hindi); kanuga oil tree (Telugu); honge (Kannada); shui huang pi (China); day mau (Vietnamese); kranji, malapari (Indonesian); mempari (Malay) [17,18]. In Indonesia, pongamia occurs mostly in the western part of Wallace line while some also can be found in the eastern part of the line: Berbak, Sembilang National Park, South Sumatra province; Berikat gulf, Bangka Belitung Province; Cape Lesung, Banten Province; Batu Karas, Pangandaran, West Java Province; Ujung Blambangan, Alas Purwo National Park, Baluran National Park, East Java province; Lovina, North Bali, Bali province; Senipah, Samboja, Sekerat, Tanjung Batu, East Kalimantan province; Sembelia, East Lombok, West Nusa Tenggara Province; and in West Seram Island, Maluku Province (Figure 1) [15,18–20]. Pongamia has many local names in Indonesia, e.g. malapari (Simeulue island), mabai (Bangka island), ki pahang laut (East Java), bangkongan and kepik (Java island), kranji (Madura island), marauwen (Minahasa, Sulawesi island), hate hira (Ternate island), butis and sikam (Timor island) [15].

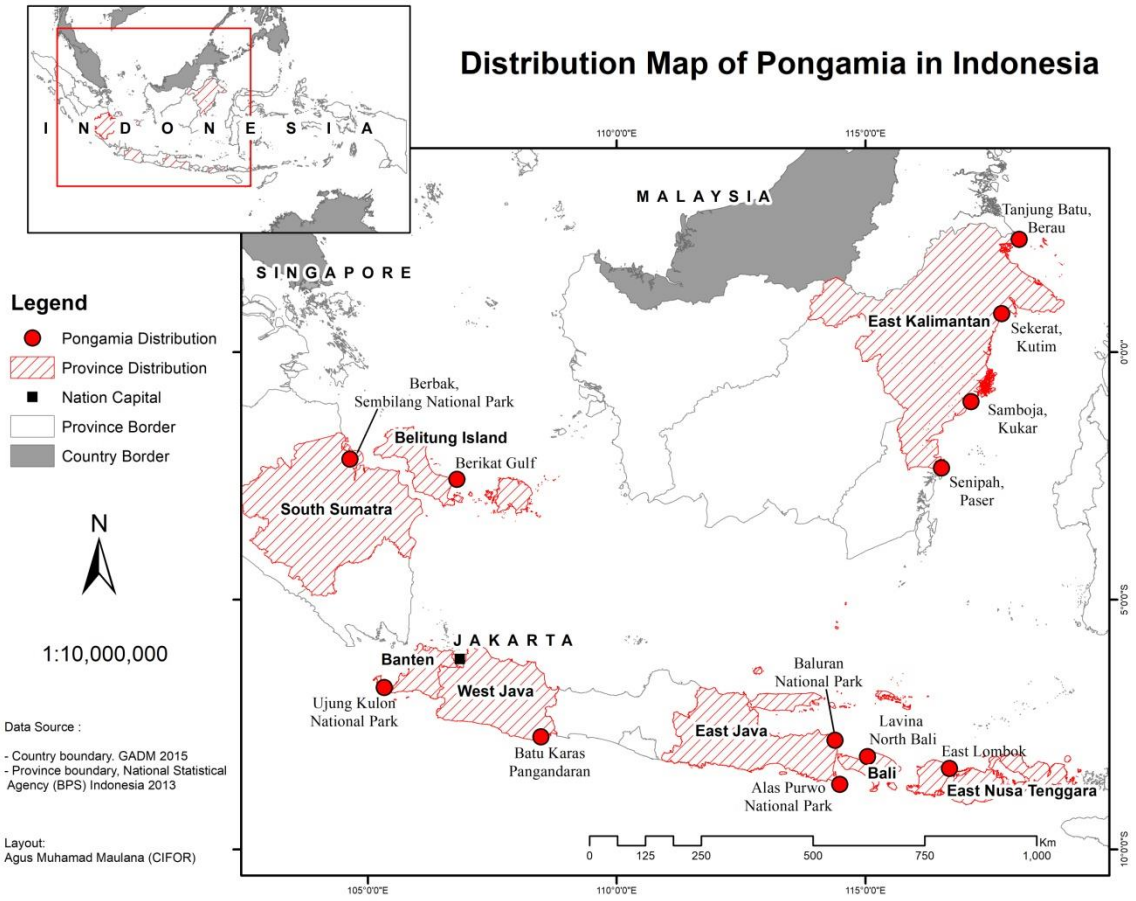

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Figure 1. Natural distribution of *Pongamia pinnata* in Indonesia

3.1.2. Growth

Pongamia naturally grows well in lowland forests on calcareous soils, in rocky beach areas, along the edges of mangrove forests, and along streams and estuaries. It is a hardy woody plant and can survive in temperatures ranging from 5°C to 50°C and at altitudes of 0–1200 m [20, 21]. It grows well in both full sun and partial shade, and can grow in most soil types, from stony to sandy to clayey. Although it is tolerant of salinity, it does not survive well in dry sands [16].

Pongamia is a semi-deciduous tree whose seeds contain non-edible oil, which can be processed into biodiesel. It is a forest tree, demands only low levels of moisture, it is drought resistant, and needs minimum input and management to grow [17,21]. It grows 15–20 m high and has a large and wide canopy [17]. With its rapid growth rate, it can reach its adult height (15-20 m) within 4–5 years [22]. Flowering usually starts after 4–5 years.

Pongamia can be propagated by generative or vegetative means. It can be vegetatively propagated from cuttings and root suckers (with new plants growing from lateral roots of the parent tree) to produce trees that are genetically identical to the parent trees [23]. Pongamia is also propagated by seeds in nursery beds or polybags, and via in-situ sowing of seeds in plantations [5,24]. It is also reported that seeds stored for three months or more result in less germination and plant vigor [24]. Seed take about one week to germinate and about 85% of seeds germinate with appropriate nursery management. There is also finding on direct relationship between seed size and germination efficiency, but only for fresh seeds [5]. The long-term viability of pongamia trees also depends on appropriate pruning practices.

3.1.3. Yields

Pongamia produces large quantities of seeds, however, yields vary according to country and environmental conditions [16,17,25–28]. There is limited information about the seed yields of pongamia in Indonesia, and most of the literature on the yields of pongamia seeds is from India and Australia [25,27–29]. This is because, pongamia grows naturally or in plantations in a wide range of areas in India while the State of Queensland is a common place for pongamia cultivation in Australia [5,27].

Pongamia can produce up to 90 kg of seeds per tree with a minimum of 9 kg per adult tree annually in India, equivalent to a potential yield of between 900 and 9000 kg per hectare [17]. This is higher than the yields reported in Australia of between 20 kg and 80 kg per tree [29]. Another report noted that, in Australia, the average annual seed production is 20 kg per tree [27]. In peninsular India, seed yields per tree range from 10 kg to more than 50 kg [28]. In Bangladesh young pongamia (15 years old or less) produce more than 25 kg of seeds per tree per year, however, yields increase as trees grow older, i.e. annual yields is more than 100 kg for 20-year-old trees and 300–500 kg for trees older than 30 years [30]. As the pongamia tree can survive up to 100 years, its production increases every year; and minimum maintenance is needed once trees reach 30 years in age [30].

3.1.4. Biofuel production potential

The most useful product from pongamia is biodiesel. Biodiesel is produced by the transesterification of bio-oil using a catalyst (e.g. potassium hydroxide (KOH) or sodium hydroxide (NaOH)) [30]. The biodiesel produced is a clean burning fuel that has no sulfur emissions and is non-corrosive. At low pressure and temperature, transesterfication produces 80% methyl ester, and 20% glycerin as by-product [17]. The major fatty acids in *Pongamia pinnata* crude oil are palmitic acid, stearic acid, linoleic acid and eicosenoic acid. The pongamia oil extracts exhibit good chemical properties and could be used as good biodiesel feedstock [17]. Fatty acid methyl ester from pongamia and other potential biodiesel plants such as *Azadirachta indica*, *Calophyllum inophyllum* and *Jatropha curcas* meet the major specifications of biodiesel standards required by American and European Standard Organization [31].

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The oil extracted from pongamia seeds is non-edible, as it has a bitter taste and a disagreeable aroma. It is yellow colored (orange to brown) and viscous. During the past few decades pongamia oil has attracted considerable attention as a potential renewable, biodegradable, eco-friendly and non-toxic fuel [17]. Several studies have determined oil yield, as below:

- 1,000 kg pongamia seeds yield 270–300 kg of crude pongamia oil, where oil content is 27–30% [26].
- The oil yield of pongamia seeds could reach up to 35% by weight [17,32].
- Some reports found yields of up to 40% [27,33].
- With the estimation of 350 pongamia trees in one hectare, it can produce ~5 tons oil ha/year [27].

Pongamia crude oil needs further processing (transesterification) to give methyl esters. About 85- 90 liters of biodiesel and 15–16 liters of glycerin (considered a by-product) can be obtained from 100 liters of pongamia crude oil by transesterification [26]. Meanwhile other report found that about 4 kg of pongamia seeds are required to produce 1 liter of crude oil, which in turn yielded 896 ml of biodiesel [34].

Pongamia can yield a considerable amount of biodiesel comparing to other biofuel species (Figure 2).

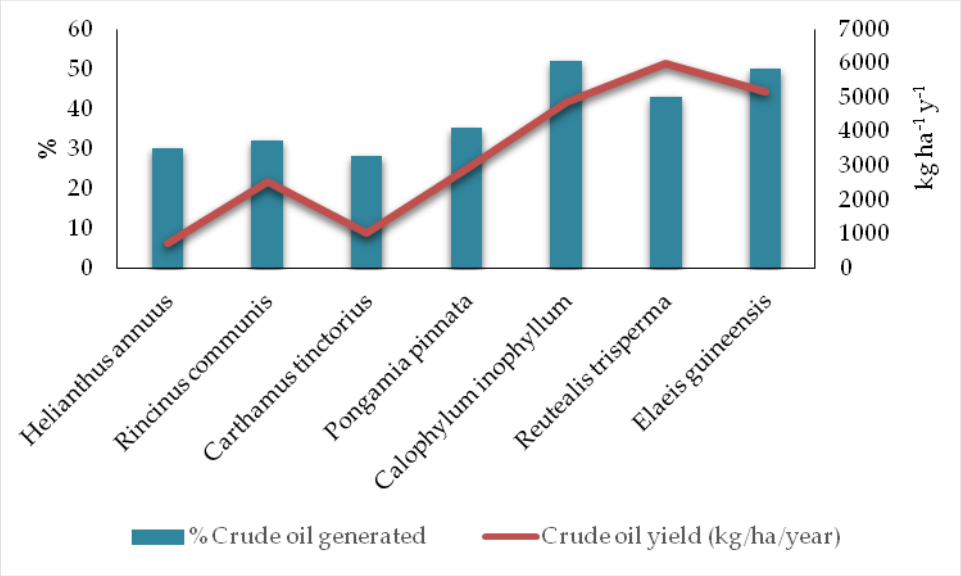

Figure 2. Amount of crude oil yielded by pongamia and other biofuel species

3.1.5. Pongamia for bio-jet fuel

One potential product from pongamia is biofuel for jets. Most planes are fueled by conventional jet fuel, which is non-renewable, costly and emits large amounts of carbon when combusted; about 2 tons of conventional jet fuel generates 1.6 tons of carbon when burned [35]. Therefore, the aviation industry is looking for renewable jet fuels [35]. However, compared to other industries, aviation has a limited range of alternative renewable fuel options that can replace fossil fuels. Bio-derived jet fuel could be a viable alternative for aviation industries [36]. *Camelina sativa*, *Jatropha* spp., *Elaeis guineensis* and algae have already used to produce fuel for several test flight; pongamia oil has yet to be tested, but has good potential [27] while land restoration, especially when compared to *Elaeis guineensis* (commonly known as oil palm) and its worldwide concern to deforestation link.

3.1.6. Other uses of pongamia

Table 2. The products and uses of pongamia tree

Attributes	Important uses	References

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Wood	Pongamia logs serve as the raw material for wood flour as lignocellulosic filler that can be further processed to produce wood–plastic composites.	[37]
	Pongamia wood is useful for making tool handles, combs, cabinets, cartwheels, posts, agricultural implements and paper pulp.	[23,28]
	Pongamia wood is used as fuelwood.	[28]
Medicine	Almost all parts of pongamia trees are used in folk medicine: juice from the roots blended with coconut milk is used to treat gonorrhea. Stem bark extract has sedative and antipyretic qualities and reduces enlarged spleens. Juice from the leaves is used to treat diarrhea, colds and coughs, and to relieve rheumatism. The fruits are used to treat abdominal tumors. The seed is used to treat keloid tumors, skin ailments and hypertension, and as an expectorant for bronchitis and whooping cough. The flowers are used to treat certain diabetic conditions. The oil is used to treat leprosy, chronic fever, skin diseases and rheumatism.	[23,38]
	A crude decoction of pongamia leaves is used as an antidiarrheal with efficacy against cholera.	[39]
Fodder	The leaves are commonly used for cattle feed and, less so, for goat feed, and are a valuable source of fodder in arid regions. Seed residue, presscake and seedcake contain much protein and is used for poultry feed; but it should not exceed 75% of feed as it contains several toxic compounds.	[22,23,28]
Fertilizer and biogas	The seedcake and leaves are used as fertilizer. Seedcake can generate biogas in household biogas generators.	[25,26]
Other services	Pongamia trees serve as windbreaks, are fire tolerant, control erosion, improve soils and are ornamental trees. The oil is used as a lubricant, leather dressing, manufacturing soap, varnish and paint. The flowers are a good source of pollen and nectar, yielding a dark honey. The bark is used to make rope. Pounded and roasted seeds used to be utilized as a fish poison. Dried leaves are useful to store with grain to repel insects.	[5,23,28,31,32,38,40–48]

3.2. The potential of pongamia for land restoration

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3.2.1. Nutrition enhancement of degraded land

Degraded land is a land that has lost its productivity [49]. Such land often has low soil nutrient content, low productivity, suffers from erosion and is unsuitable for growing crops. There are two main ways of restoring degraded land: (i) physical, technical or engineering restoration or (ii) biological restoration [50]. However, the best way is to integrate these two methods.

Pongamia trees have several benefits to restore the degraded land. A study showed that a 5-year-old pongamia plantation has a carbon sequestration potential of around 49.28 t ha^{-1} [51]. Pongamia is capable of withstanding drought stress, can grow on saline soils and needs little topsoil as it has a dense network of lateral roots and thick long taproots. Pongamia plantations can help alleviate compaction and crusting [52]. It is a sturdy plant with no special nutritional requirements and can grow in extreme environmental conditions. It is tolerant to soil sodicity, pH imbalances, high temperatures, heavy metal contamination, drought and poorly drained soils. Consequently pongamia can achieve phytostabilization, i.e. the long-term stabilization and containment of pollutants [53,54]. Iron, chromium, copper, manganese and magnesium in fly ash dykes have been phytostabilized by establishing pongamia plantations on the dykes [53]. Therefore, establishing pongamia biofuel plantations on degraded land can be a win–win solution for energy production and land restoration [50,52–55].

3.2.2. Nitrogen fixing

Chemical nitrogen fertilizer is widely used for growing crops in Indonesia. However, it is costly and its production causes high levels of greenhouse gas emissions [56]. The restoration of degraded land also needs the stabilization of nitrogen content. Pongamia is a leguminous tree that fixes biological nitrogen, while also producing the raw materials for biofuel [57,58]. In contrast, other common biofuel crops, such as canola, sugarcane, sweet sorghum, maize and woody trees (e.g. eucalyptus and willow), demand nitrogen to grow rather than produce nitrogen [57]. Pongamia produces nitrogen throughout its life [57]. It fixes nitrogen in root nodules through symbiosis with soil bacteria that are collectively called rhizobia[1] [57]. Therefore, the cultivation of pongamia together with agricultural crops can potentially have a good agricultural yield.

3.3. Community involvement

Fuel production and distribution are often considered as the state obligation, however, local communities as the stakeholder directly affected by the fuel shortage, their potential contribution [59] should be in account during pongamia cultivation process. Such contribution can oversee the local capacity building in both technical and administrative [60, 61] that can strengthen pongamia cultivation in a landscape scale. People's involvement can enhance local income, innovative spirit, technical proficiency and enthusiasm by distribution degraded land (the area surrounded by the community) or using their own degraded land for pongamia cultivation. It may also increase transparency and accountability for all parties, i.e. local communities, government, investors; and for the sense of responsibility and encouragement to support the land restoration efforts from the mutually binding interests.

4. Conclusions

Pongamia trees are well suited to growing in adverse environmental conditions. This tree can grow in most soil types, in partial shade or full sun, and at various temperatures. Pongamia is a

[1] Rhizobia is an endophytic bacterial community living in plant tissue (root nodules) [56].

multipurpose tree that fixes soil nitrogen and improves the soil health, and produces large amounts of non-edible oil for biodiesel. It can produce such bioenergy on non-cropping and degraded land that is not suitable for food production. As the large area of degraded lands in Indonesia delivers limited benefits to humans and nature, restoring such land through pongamia cultivation can provide an opportunity to enhance ecosystem services delivery and reverse the loss of biodiversity. Although several other species produce biofuel (e.g. oil palm, coconut, jatropha), with its multiple benefits (Table 2), pongamia is a prime candidate for planting as a bioenergy feedstock on degraded land.

However, further studies of pongamia, focusing on up-to-date production technology, long-term plantation management, community involvement, various value-added options (e.g. understory crop association), identifying potential biofuel producers and consumers, developing effective business models for various biofuel stakeholders, and the feasibility of building stable biofuel markets, could help to fill knowledge gaps in Indonesia and benefit scientific communities, policymakers and other stakeholders.

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