CHAPTER 11

Pongamia as a potential biofuel crop

Oil content of *Pongamia pinnata* from the best provenance in Java, Indonesia

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Abstract: *Pongamia pinnata* (L.) Pierre is a fast-growing, leguminous and multipurpose tree species. It grows on degraded and marginal land in South and Southeast Asia. It produces non-edible seeds, the oil of which is a potential biofuel. In Indonesia, pongamia is widely found on all islands, but mostly to the west of the Wallace Line, in Banten, East Java, South Sumatra and West Java provinces. The economic viability of pongamia depends on the number of seeds per tree and the oil content of seeds. Studies on pongamia in Indonesia, with oil extracted using a simple mechanical expeller press, revealed that trees growing in Ujung Kulon National Park in Banten Province produce seeds with a higher oil content (15.59%) than those growing in the provinces of East and West Java. In this study, the oil content of 48 individual trees from Ujung Kulon National Park were analysed using a solvent extraction method. As a control, bulk seed was extracted using two different methods: 1) a Fabricant mechanical screw expeller press; and 2) solvent extraction. The results showed highly significant variance in oil content. Oil production of individual trees processed using the solvent extraction method reached 44% (varying from 26.61% to 44.68%), substantially higher than those using mechanical pressing at only 15% to 19%. Findings show that genetic factors, extraction machines and method of extraction can all influence pongamia oil production. The quality and genetic diversity of the seed source is also extremely important for industrial plantation forest programmes for bioenergy and land restoration in Indonesia.

Keywords: Biofuel crop, crude oil content, Pongamia pinnata, solvent method
Link: https://www.cifor.org/knowledge/publication/7903/
This is an edited version of an article previously published in IEEE (Hasnah et al. 2021).

11.1 Introduction

Pongamia pinnata (pongamia) is a legume tree with seed containing oils and fatty acids, which has been identified as a possible source of biofuel as well as having medicinal value. It is one of the few nitrogen fixing trees (NFTs) to produce seeds containing 30% to 40% oil suitable for biodiesel production (Chaukiyal et al. 2000; Dwivedi et al. 2011; Bobade and Khyade 2012; Samuel et al. 2013). The species has several benefits including: (i) a higher recovery and quality of oil than other crops; (ii) no direct competition with food crops as it is a non-edible source of fuel; and (iii) no direct competition with existing farmland as it can be grown on degraded and marginal land. In addition, as a legume it also fixes nitrogen from the soil, thus minimizing the need for fertilizers (Balooni and Singh 2001; Lal 2006; Kesari and Rangan 2010). Furthermore, pongamia flowers attract honeybees which in turn can help support rural economies. Due to its deep roots, it is also drought tolerant and can survive temperatures ranging from 5°C to 50°C. Pongamia is found in coastal areas, along limestone and rocky outcrops, and along the edges of mangrove forests, tidal streams and rivers (Sidiyasa et al 2012; Ramachandran and Radhapriya 2016).

The most useful product from pongamia is biodiesel (Abadi et al. 2016). In India, billions of pongamia trees are cultivated commercially for a sustainable biodiesel industry (Dwivedi et al. 2011). The aviation industry is looking for renewable jet fuels (Hendricks et al. 2011), and bio-derived jet fuel could be a viable alternative for the industry (Islam and Bari 2016).

It is well known that success in the establishment and productivity of forest tree plantations is determined largely by the species used and its seed source or provenance. A provenance is the original geographic area from which seed or other propagules are obtained (Zobel and Talbert 1984). Pongamia has a varied habitat distribution and can grow in a wide range of conditions. In Indonesia, the species occurs mostly to the west of the Wallace Line, though some trees can also be found to the east. On Java, pongamia can be found in Ujung Kulon National Park (Banten Province), Pangandaran (West Java Province), Alas Purwo National Park (East Java Province), and in other provinces (Djam'an 2009; Sidiyasa et al 2012; Aminah et al. 2017; Jayusman 2017). The wide natural distribution of pongamia offers a large geographical area from which to select the best provenances for genetically improved seed. This genetic variation could then be used in selection and breeding programmes.

Studies on *pongamia* in Indonesia, with oil extracted using a simple mechanical expeller press, revealed that trees grown in Ujung Kulon National Park in Banten Province produced seeds with a higher oil content (15.59%) than those grown in the provinces of East and West Java. However, this content was lower compared to results from various provenances in other countries using Soxhlet extractor equipment. To ascertain the maximum oil potential of pongamia, this study analysed the oil content of pongamia seeds derived from 48 individual trees growing in Ujung Kulon National Park. The study compared two improved extraction methods and compared these with available literature.

11.2 Materials and methods

11.2.1 Survey and seed collection

Seeds used for this analysis were obtained from Ujung Kulon National Park (UKNP) in Banten Province, which based on studies from 2015 and 2016, was considered the best provenance for pongamia on Java (Leksono et al. 2015; Jayusman and Pudjiono 2017). The park is located on the western tip of Java (Figure 1), and has a total area of 122,955 ha comprising a terrestrial area of 78,619 ha and marine area of 44,337 ha (UKNP Office 2015). The area includes the volcanic island group of Krakatoa in Lampung Province, and other islands including Panaitan, as well as smaller offshore islets such as Handeuleum and Peucang in the Sunda Strait.

A survey was conducted in 2018 to identify and select pongamia parent trees for seed extraction and genetic material. The seed from 48 trees was collected in 2019 for oil content analysis in 2019 and 2020.

The study was a continuation of previous studies in 2015 and 2016, which used pongamia genetic material and provenances from three areas of natural forest – Ujung Kulon National Park (Banten Province), Batu Karas-Pangandaran (West Java Province) and Alas Purwo National Park (East Java Province) – representing the natural distribution of pongamia on Java (Leksono et al. 2015; Jayusman 2017). Table 1 presents the site characteristics of the three provenances.

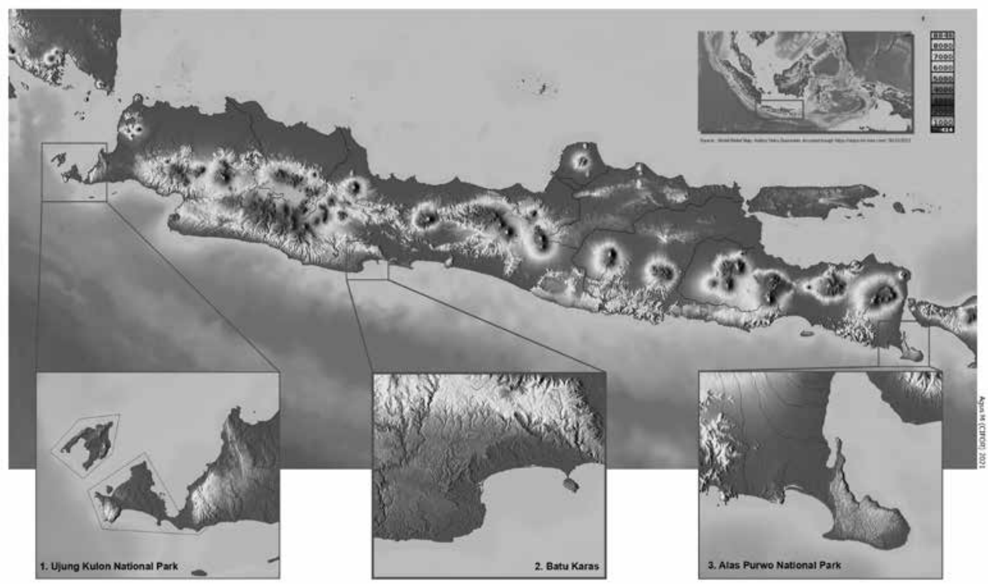

Figure 1. Location of Ujung Kulon National Park (Banten Province), Batu Karas-Pangandaran (West Java Province) and Alas Purwo National Park (East Java Province) Indonesia.

Table 1. Site characteristics of three provenances on Java

Characteristic*	Ujung Kulon (Banten)	Batu Karas (West Java)	Alas Purwo (East Java)
Latitude (South)	06°52’17”	07°41’15”	8°26’45”
Longitude (East)	102°02'32"	108°39'32"	114°20’16“
Altitude (m asl.)	0–8	0–4	0–15
Rainfall (mm per year)	3,250	2,987	2,079
Temperature (°C)	25–30	25–30	25–30
Dry season	May – September	May – September	June – October

*Sources: Leksono et al. 2015; Jayusman 2017

11.2.2 Materials and equipment

Fruit pods (300 g – 400 g) were opened manually to release seeds, which were then broken and divided into three seed samples. Materials for crude oil analyses included n-Hexane, water, paper filters and seeds. Tools used to conduct the research included an analytical balance, dry seed blender, electric stove, distillation set, stone boiler, thermometer, glass funnels and glass beakers.

Two pieces of equipment were used for extracting oil from the pongamia seeds: 1) a Fabricant mechanical screw expeller press and 2) a Soxhlet extractor. Pongamia seed pressing and oil analyses were conducted in the Bioenergy Laboratory at the Research and Development Centre for Forest Biotechnology and Tree Improvement (P3BPTH) in Yogyakarta.

11.2.3 Methods

The study applied two improved methods to extract pongamia oil: 1) mechanical pressing for bulk seed and 2) solvent extraction for bulk seed and individual seeds. Mechanical pressing is one of the oldest methods used for oil extraction. In principle, the seeds are placed between barriers where the volume available to the seed is reduced by pressing, thereby forcing oil out of the seeds. The solvent extraction method is, amongst other factors, based on the ability of the solvent to dissolve oils and to extract them from the seeds. It is the most commonly used method, and usually carried out either as a batch or continuous process (Nde and Foncha 2015).

11.2.4 Oil extraction: The mechanical press method

This method required more samples than the solvent method. The process started with sun drying the seed samples for one to two days, or in a cabinet dryer at 80°C to obtain dry seed with a moisture content of 8% to 12%. Prior to pressing, readied samples were heated to 75°C to 80°C for five to ten minutes to ‘loosen’ the oil from the cake.

Figure 2. Pongamia oil extraction process using a mechanical press: (a) pongamia pods/fruits, (b) dry pongamia seeds, (c) pressing process, (d) filtering process, (e) pongamia oil

To ease the flow of oil, the seeds were gradually inserted into the screw press until raw oil and residue were released. This process was done repeatedly depending on the condition of the seed material. Usually, raw oil could only be extracted after the resulting residue was completely dry. The oil content could then be quantified once it had gone through a filtering process (Figure 2).

11.2.5 Oil extraction: The solvent method

The seeds were ground into fine particles of around 20 g using an appropriate size blender. The Soxhlet apparatus was set up, and 150 ml of hexane liquid solvent was added from above to a thimble made of filter paper, then heated to evaporate the solvent. N-hexane is commonly used in chemical extraction because of its ability to extract more oil than other methods (Bhuiya et al. 2015). The temperature was stable at 75°C to 80°C during the process. Reflux was achieved through a condenser attached to the main chamber. The oil extraction process was carried out until all of the oil had been released from the seeds, as indicated by the n-hexane colour indicator drip returning to its pre-process colour. The resulting material was a mix of raw oil and n-hexane solution. To obtain pure pongamia oil, the raw material was separated using a distillation process (Figure 3).

Figure 3. Pongamia oil extraction process using the solvent method: (a) seed grinding, (b) thimble in chamber, (c) oil extraction process by Soxhlet extractor, (d) raw oil and n-hexane solution, (e) distillation process, (f) pongamia oil

11.2.6 Data analysis

The pongamia oil content was determined in order to examine variance in oil content potential. The formula used to calculate oil content parameters was as follows (BSN 2017):

$$\text{Oil content} = \frac{\text{Weight of extracted oil}}{\text{Seed weight}} \text{ X } 100\%$$

Analysis of variance between trees in the sampling location (Ujung Kulon National Park) was performed using individual tree data (Y_{ij}) for oil content with the following linear model:

$$Y_{ij} = \mu + F_i + \varepsilon_{ij}$$

where, μ is the overall mean, F_i is the *i*-th tree or family effect, and ε_{ij} is the experimental error for Y_{ij}.

SAS (Statistic Analysis System) ver. 9.0 was applied to run the analysis of variance.

11.3 Results and discussion

11.3.1 Oil content of pongamia oil

Pongamia oil content extracted from seeds from the three provenances in an earlier study using a simple mechanical screw expeller press made by a home industry workshop is presented in Table 2.

The results of the pressing procedure (Table 2) using a simple screw expeller press demonstrate that the average oil content potential from dry seed is 14.4%. Oil content varied significantly between the three provenances, ranging from 13.13% to 15.59%, with the highest oil content obtained from the Ujung Kulon National Park provenance. High variance in oil content between samples from the three provenances suggested that an improvement programme through pongamia provenance selection could be implemented and be very effective.

In forests, tree variations occur due to many factors, and most certainly include provenance or geographic race variations. Genetically controlled geographic differences are often large. Differences can be of key importance and the success of any tree improvement programme depends upon knowledge and use of geographic variation within the species of interest (Wright 1976; Zobel and Talbert 1984). Therefore, the determination of what constitutes a potential geographic source is very important when a tree improvement programme is implemented.

However, the oil content of trees from the three study provenances (Table 3) was lower compared to the results of provenance variance in Madhya Pradesh, India using a Soxhlet extractor, which ranged from 33.31% to 39.01% (Rahangdale et al. 2014). Using the same method (solvent extraction), seeds from Carmen and Agusan del Norte in the Philippines produced pongamia oil content of 28.18% to 41.32% (Razal et al. 2012), while seeds from Queensland and the Northern Territory in Australia had oil content of 36.7% to 37.74% (Arpiwi 2013). Other researchers have also reported pongamia oil content in the range of 27% to 39%. with extraction from kernels using traditional expellers yielding up to 26% oil (Meher et al. 2008), and varying between 30% and 40% in India (Dwivedi et al. 2011). This

Table 2. Oil content of pongamia from three provenances in Indonesia

Sample	Oil content (%) *		
	Ujung Kulon (Banten)	Batu Karas (West Java)	Alas Purwo (East Java)
1	15.82	14.25	13.05
2	15.44	14.54	13.23
3	15.52	14.67	13.12
Average	15.59	14.49	13.13

*Source: Jayusman and Pudjiono 2017

Table 3. Pongamia oil content from the best provenance by extraction method

No.	Mechanical Press Method			Solvent Method		
	Seed weight (g)	Oil content (g)	Oil content (%)	Seed weight (g)	Oil content (g)	Oil content (%)
1	121.68	22.06	18.13	21.25	5.81	27.34
2	146.00	23.24	15.92	20.53	5.83	28.40
3	122.72	22.46	18.30	21.46	7.55	35.18
4	130.90	21.6	16.50	21.92	7.02	32.03
5	146.00	28.62	19.60	20.86	8.19	39.26
	Average		17.69			32.44

would suggest that generally, pongamia seed has an oil content in excess of 25%, and that oil content may vary depending on provenance, time of collection, age of tree and processing method or equipment used (Leksono et al. 2014).

To find the maximum oil potential of pongamia seed from the Ujung Kulon provenance, oil content verification was carried out in 2019–2020 using better equipment and methods: 1) a mechanical pressing method using a Fabricant screw expeller press (Figure 2); and 2) a solvent method using a Soxhlet extractor (Figure 3). Both processes produced more oil (Table 3) than the screw press technology used previously (Table 2).

The results in Table 3 show that a mechanical Fabricant screw expeller press produced 2% – 25% more oil (in the range of 15.92% – 19.60%) than the simple screw press (15.44% – 15.82%). This was because the pongamia residue (waste from pressed seeds) from extraction using the simple screw press was still thick and wet, and the maximum amount of oil had not been extracted. In contrast, using the Fabricant screw expeller press was a more optimum seed pressing system and the waste was very thin and dry (Figure 2). Oil content using the solvent method varied from 27.34% to 39.26% (Table 3), which was much higher than from both screw expeller presses, despite being from the same provenance. Oil content was not significantly different to the results of mechanical extraction using the same method reported in previous research. This suggests that differences in oil content are not only influenced by genetic factors, but also by the processing method and the quality of equipment used.

Currently, there are three methods for extracting oil from seeds: 1) hydraulic press extraction, 2) expeller press extraction, and 3) solvent extraction. Of the three processes, solvent extraction scores highly over the other two methods, and has the following advantages: 1) maximum oil recovery, 2) lower working costs, 3) cheaper prices for end users, 4) production able to meet demand, 5) extracted oil has less sediment, and 6) solvent loss is low (Pon Pure Chemical Group 2018). Solvent or chemical extraction using n-hexane has been found to be a highly effective method of oil extraction because of its consistent performance and high oil yield. Consequently, it is the most common method (Bhuiya et al.

2015). Solvent methods have been developed in many countries and have proven to produce high oil content. Due to the many advantages of solvent extraction, this process needs to be developed further in Indonesia.

11.3.2 Oil content of trees from Ujung Kulon National Park

Analyses of pongamia oil from 48 parent trees from the same provenance (Ujung Kulon National Park) showed the oil content variance of trees or families to be highly significant (Table 4). The significance of family variance observed in this study indicates that there is significant potential for increasing gains through breeding programmes.

Variance in oil content of seed from 48 individual parent trees from the Ujung Kulon National Park provenance (mean and rank) is presented in Table 5. The oil content of seeds

Table 4. Analysis of variance of oil content between individual trees

Source of Variance	df	Sum of Square	Mean of Square	F Value	Pr > F
Tree	47	2093.85	46.5501**	4.00	<.0001
Error	78	868.55	11.1352		
Total	125	2962.40			
		R-Square	Coef. Variance	Root MSE	Mean
		0.70	9.81	3.33	34.01

Table 5. Mean oil content (%) for individual trees

Rank	Tree No.	Oil Content	Rank	Tree No.	Oil Content	Rank	Tree No.	Oil Content
1	16	44.68	17	15	34.95	33	19	31.96
2	7	43.93	18	9	34.87	34	14	31.91
3	44	43.64	19	27	34.55	35	33	31.56
4	11	42.44	20	21	34.52	36	25	30.83
5	10	40.95	21	41	34.05	37	50	30.82
6	38	40.10	22	26	34.01	38	48	30.82
7	8	40.02	23	20	33.76	39	22	30.60
8	30	38.47	24	29	33.72	40	49	30.51
9	18	37.61	25	23	33.52	41	40	30.47
10	46	37.00	26	24	33.50	42	28	30.41
11	6	36.57	27	12	33.21	43	39	29.66
12	31	36.25	28	13	32.94	44	45	29.46
13	36	35.43	29	42	32.64	45	17	29.45
14	32	35.12	30	3	32.42	46	4	29.27
15	1	34.98	31	34	32.35	47	2	29.22
16	35	34.97	32	5	32.23	48	47	26.61

from these parent trees averaged 34.01%, and ranged from 26.61% to 44.68%. These results clearly show the potential of pongamia to provide oil content of 40% when using solvent extraction, as reported in several countries. The oil content was higher than the oil content of seed using the same method observed in 45 tree accessions from three provinces in southern Thailand, where oil content varied from 26.65% to 33.12% (Panpraneecharoen et al. 2014) and was also higher than oil content in various studies from other countries (Meher et al. 2008; Dwivedi et al. 2011; Razal et al. 2012; Arpiwi 2013; Rahangdale et al. 2014).

The success of any tree improvement programme largely depends on the breeding strategy and the selection practices used to increase the expected genetic gain (Zobel and Talbert 1984). Improvement programmes begin by selecting trees in natural stands or unimproved plantations based on their phenotypic values. Selected trees are then mated, and their progenies are established in such a way that they can be used as a source of selection for the next generation of improvement (Burdon and Shelbourne 1972; Namkoong et al. 1988). Findings and the advantages of *Pongamia pinnata* indicate it is a viable species with significant potential for bioenergy production, and for forest rehabilitation and land restoration programmes in Indonesia.

11.4 Conclusion

Pongamia pinnata is a potential bioenergy species with oil content potential of up to 44.68% from the best provenance using a solvent extraction process. Study findings show that genetic factors, extraction machines and method of extraction can all influence *pongamia* oil production. Improvements to pongamia trees for biofuel, based on the oil content potential of trees from the best provenance, could produce genetically improved seed to increase oil content productivity. The quality and genetic diversity of the seed source is also extremely important for industrial plantation forest programmes for bioenergy and land restoration in Indonesia.

For future research, variance between parent trees (families) in pongamia oil content will be used to establish progeny tests in several sites. Tested progenies will gradually be converted into seedling seed orchards through combinations within plots and between families until only seed-producing trees remain to produce genetically improved seed.

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