CHAPTER 12

Calophyllum inophyllum

A viable prospect for green energy and landscape restoration?

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Abstract: Indonesia has approximately 14 Mha of degraded lands. These lands have potential for growing biofuel species to meet needs for energy security, income generation and land restoration. One promising species, *Calophyllum inophyllum*, is suitable for growing on 5.7 Mha of degraded land in Indonesia, and could contribute to green energy production and restoration of this degraded land. During its early growth stage, the species can grow by up to one metre per year and is tolerant to harsh environmental conditions. Its seeds provide high levels of non-edible oil, thus making it ideal for biodiesel production. In addition, waste and by-products from the biodiesel production process can be used as raw materials in the pharmaceuticals and cosmetics industries, and as compost for soil enrichment. Growing various cash crops together with *Calophyllum inophyllum* in agroforestry systems can provide extra income for farmers, thus creating added value for *Calophyllum inophyllum* cultivation.

Keywords: *Calophyllum inophyllum*, biofuel, income, land restoration, waste utilization
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12.1 Introduction

Land degradation has become a serious problem in many tropical countries due to population growth and rapid economic development. The Government of Indonesia has introduced a number of initiatives to reverse land degradation, including community and social forestry schemes, and aims to restore 14 million hectares of degraded land and 2 million hectares of degraded peatlands by 2030 (MoEF 2018). Restoration of degraded landscapes through natural regeneration, afforestation, reforestation, agroforestation and climate smart agriculture (Lamb et al. 2005; Roshetko et al. 2007; Chazdon and Guariguata 2016) can provide opportunities to reverse biodiversity loss and enhance the delivery of ecosystem services (Rahman et al. 2018). Around 8.9 million hectares (Mha), or 53% of degraded lands identified in Indonesia, have potential for growing biofuel species such as *Calophyllum inophyllum* (5.7 Mha), *Pongamia pinnata* (4.4 Mha) and *Reutealis trisperma* (3.8 Mha) (Jaung et al. 2018).

Calophyllum inophyllum, known locally as '*nyamplung*', is ideal for producing biodiesel. It produces non-edible seeds will high kernel oil content, which can be harvested without the need to cut down trees. The species is tolerant to harsh environmental conditions and requires little maintenance in its cultivation. In Indonesia, it has a wide natural distribution from Sumatra in the west to Papua in the east, and from Java in the south to Kalimantan in the north (Leksono et al. 2014). Plantations of *C. inophyllum* in Indonesia, such as those in Wonogiri (Central Java), Gunung Kidul (Yogyakarta), Lasem (East Java), Pangandaran (West Java) and West Bali (Bali) show it is possible to combine the species in intensive silviculture and agroforestry systems (Leksono et al. 2014).

During biodiesel production processes, depending on the feed stock used, up to 50% of produce constitutes residues (Leksono et al. 2014). These include wastewater, minerals, resins, strained solids, and glycerine. If not properly processed and utilized, these residues can be harmful for the environment and for human health. *C. inophyllum* residues can easily be used to maintain the environment and can enhance the economic viability of biodiesel production processes (Leksono et al. 2017).

In recent decades, the global energy crisis and increasing demand for biofuel has prompted research into the advantages of *C. inophyllum*. This paper provides an overview of the species and its applications in green energy production and landscape restoration. It describes plant growth, biofuel content, economic potential from combinations with other commodities in agroforestry systems, and the usefulness of its by-products when used for biodiesel production.

12.2 Landscape restoration

Successful landscape restoration depends not only on the rehabilitation of biodiversity and ecosystems, but also on the choice of species used, their location in the landscape, and how they can help fulfil local people's needs (Lamb et al. 2005). Equally, for a landscape to be sustainable, the production of food and energy should coexist alongside biodiversity (Tilman et al. 2009). Perennial bioenergy crops can be planted to restore degraded or marginal lands that would otherwise be costly to restore (Lemus and Lal 2005; Tilman et al. 2009). In Indonesia, *C. inophyllum* has significant potential for the restoration of approximately 5.7 Mha of degraded lands. These lands are predominantly in Sumatra (2.7 Mha), though smaller areas have been identified in the Java and Bali regions (0.08 Mha) (Wiraguna et al. unpublished).

C. inophyllum can grow in hot temperatures. However, it is not suited to high elevations, cold regions, or very dry conditions (Prabakaran and Britto 2012). The species tolerates light to medium soils, i.e., sand, sandy loam, loam and sandy clay loam, but can also grow in soils with impeded drainage or seasonal inundation. It also tolerates calcareous rocky and saline soils (Atabani and Cesar 2014). It is a hardy tree, native to tropical coastal areas and can withstand high winds, salt spray and drought. Due to its tolerance to harsh environmental conditions, the species has been planted in southern areas of Java for conserving coastal areas and providing windbreaks, and for rehabilitating waterlogged land and rocky calcareous soils (Leksono et al. 2010). It has also been used for rehabilitating rocky soil in Gunung Kidul, Yogyakarta Province (Leksono et al. 2017).

12.3 Species growth, and development of agroforestry practices

Young *C. inophyllum* trees can grow up to one metre in height per year for their first few years, before their growth rate slows in subsequent years. A report by Soerlanegara (1994) indicates that individual trees in *C. inophyllum* stands in Malaysia reached diameters of 50 cm at breast height in 70 years. Growth of *C. inophyllum* trees in Indonesia varies depending on population origin and land characteristics. In our study, *C. inophyllum* plantations were grouped into stands on marginal land in Gunung Kidul and mineral land in Wonogiri (Table 1). Plant spacing of 5 m x 5 m was applied to allow enough space for tree canopy growth (Leksono et al. 2015). Planting techniques that combined intensive silviculture and agroforestry systems were used (Leksono et al. 2014).

12.3.1 Plantation trials on marginal land

The characteristics of the marginal land used for *C. inophyllum* plantation trials in Gunung Kidul District in Central Java are shown in Table 1. Genetic material for the species trials were collected from eight populations from different islands in Indonesia: Padang in Sumatra, Gunung Kidul in Java, Selayar in Sulawesi, East Bali, Yapen in Papua, Dompu in West Nusa Tenggara, Ketapang in Kalimantan and Sumenep in Madura. Trials were conducted using 25 square plots with 6 replications each making 150 trees from each population source, and 1,200 trees in total (Leksono 2018).

Table 1. Characteristics of the lands used for *C. Inophyllum* plantation trials

Characteristic	Gunung Kidul*	Wonogiri*
Latitude (South) **Longitude (East)**	7°53'25" 110°32'55"	7°32' 110°41'
Elevation (m asl)	150	141
Rainfall (mm per year)	1,809	1,878
Temperature (°C)	21–32	20–38
Soil nutrients **N (%)** **P (ppm)** **K (me per 100g)**	 0.27–0.35 2.48–6.17 0.11–0.19	 0.04–0.07 1.80–4.07 0.11–0.13
Soil texture	clay, thin solum, rocky soil	Clay

*Source: Hasnah and Windyarini 2014

Table 2. shows that after five years, all populations had survival rates similar to or higher than the local population in Gunung Kidul (≥ 69%), with rates ranging from 69% for the Padang population to 80% for Ketapang. A survival rate of 60% is normally considered satisfactory in forestry plantation programmes (Lamichhane and Thapa 2011). As our results indicate all tested populations adapting well to the trial site, all populations could be cultivated in Gunung Kidul (Leksono 2018).

However, in our trials, the heights and diameters of different populations varied quite significantly after five years (Table 2). Variations in growth traits in seedlings and germination have also been reported by Hasnah and Windyarini (2014) and Palanikumaran et al. (2015), while variations in oil content, and fruit and seed size have been reported by Hasnah and Windyarini (2014) and Leksono et al. (2014). Variability between populations has generally been attributed either to the genetic characters of source populations (Uniyal and Todaria 2003), or to influences from parent plants' environments (Fenner 1991). Since all populations are growing at the same site, such growth variations could be attributed to genetic differences (Leksono 2018). Some genotypes are specifically adapted to marginal conditions and show strong vegetative growth during their early years. This growth can vary according to latitude, elevation, soil or rainfall differences, depending on where trees are grown (Habjorg 1972a, 1972b; Eriksson and Jonsson 1986; Sukhor et al. 1989; Luomajoki 1999; Lee et al. 2015). An analysis of 11 populations of *C. inophyllum* using DNA (RAPD) markers showed that genetic differentiation between Indonesian islands was insignificant, but differentiation was significant within populations and between individual trees (Nurtjahjaningsih and Widyatmoko 2012). Considerable variation in the performance of this species should thus be expected when exposed to different environmental conditions. Further planting of the populations recommended here should be restricted to sites similar to the trial site. Stable genotypes should also be identified across the site (Sukhor et al. 1989).

Table 2. *C. Inophyllum* growth in provenance trials on marginal land

Population	Year 1		Year 2			Year 3			Year 4			Year 5		
	SR	H	SR	H	D	SR	H	D	SR	H	D	SR	H	D
Padang	94	1.02	81	1.16	1.06	71	1.61	1.33	69	2.14	1.89	69	2.57	2.30
Gunung Kidul	89	1.00	77	1.44	1.47	71	1.97	1.84	71	2.54	2.59	69	3.20	3.50
Selayar	87	0.78	82	1.56	1.32	75	2.14	1.95	73	2.86	2.92	73	3.53	3.79
East Bali	86	0.87	78	1.80	1.56	70	2.38	2.21	69	3.06	3.36	70	3.90	4.42
Yapen	86	0.99	84	1.55	1.38	79	1.94	1.95	79	2.37	2.88	78	3.11	3.75
Dompu	85	0.81	80	1.43	1.24	69	1.98	1.76	70	2.56	2.55	69	3.30	3.52
Ketapang	85	0.80	86	1.75	1.29	81	2.22	2.04	80	2.98	3.39	80	3.68	3.84
Madura	82	0.69	81	1.61	1.29	72	2.16	1.94	69	2.92	3.06	71	3.65	3.88

SR = survival rate (%); H = height (m); D = diameter (cm)

Source: Leksono 2018

Table 3. Growth in a *C. Inophyllum* provenance seed stand on mineral land

PMP	Year 1			Year 2			Year 3			Year 4			Year 5			Year 6		
	SR	H	D	SR	H	D	SR	H	D	SR	H	D	SR	H	D	SR	H	D
I	98	0.45		88	2.56	0.26	90	4.62	4.85	90	6.53	743	90	8.04	10.92	73*	9.39	12.63
II	100	0.39		95	3.16	0.33	95	5.11	5.54	95	6.72	8.50	95	7.97	12.04	73*	10.35	14.32

PMP = permanent measuring plot; SR = survival rate (%); H = Height (m); D = Diameter (cm)

*after first thinning

Source: Leksono et al. 2017

12.3.2 Plantation trials on mineral land

The characteristics of the mineral land used for *C. inophyllum* plantation trials in Wonogiri, Central Java, are shown in Table 1. A total of 800 trees were planted using source material originating from Gunung Kidul. The growth rates for these trees are shown in Table 3. Over the first five years, *C. inophyllum* performed well, with a 95% survival rate. After the first thinning with 10% intensity, in year six, the survival rate fell to 73%, with a mean height of 10.35 m and diameter of 14.32 cm. In these plots, 3.25% of trees began flowered at 1.5 years after planting, increasing each year to reach an annual flowering rate of 25.71% (Windyarini and Hasnah 2014; Leksono et al. 2015).

These results are much better than seen in some other locations, where the first flowering was generally at 7–8 years after planting (Bustomi et al. 2008). *C. inophyllum* growth on mineral soil in Wonogiri exceeded growth on marginal land in Gunung Kidul. It is possible that environmental conditions in Wonogiri are more favourable for *C. inophyllum* growth than those in the places of origin (Hasnah and Windyarini 2014). The main difference between Wonogiri and Gunung Kidul is the thickness of the soil layer; at 30 cm, Gunung Kidul has a thinner soil layer than Wonogiri (Wiyono et al. 2006).

12.3.3 *C. inophyllum*-based agroforestry

Through the Yogyakarta Forest Management Unit (FMU), the Yogyakarta Special Region Government has established 25 ha of *C. inophyllum* plantations to support a biofuel processing plant in Baron Techno Park in Gunung Kidul, which has a production capacity of 500 kl per batch per day. The plantation seeds were sourced from populations in Dompu in West Nusa Tenggara Province and Purworejo in Central Java.

These plantations are managed by the Wono Lestari farmer group in Menggoran Village, Playen Subdistrict, Gunung Kidul District, using agroforestry planting techniques with maize, cassava, peanuts, soybean and fodder grass. Each 25 ha planted with these agricultural commodities can provide additional incomes for farmers with annual yields and earnings as follows:

60 tons of maize @ IDR 2,000 per kg = IDR 120 million;
60 tons of cassava @ IDR 1,200 per kg = IDR 72 million;
20 tons of feed grass @ IDR 500 per kg = IDR 20 million;
1 ton of peanuts @ IDR 3,000 per kg = IDR 3 million;
0.5 tons of soybeans @ IDR 4,500 per kg = IDR 2.25 million.

This is equivalent to total earnings of IDR 217.25 million for 25 ha, or IDR 8.69 million per ha annually (Leksono 2016).

Further, farmers practicing agroforestry systems in Wonogiri use *C. inophyllum* with various annual crops, such as paddy, peanut and maize, with honey also produced in the plantations. Over a full rotation (i.e., 35 years), economic returns from each individual crop grown with *C. inophyllum* vary. Maize and paddy can only be grown for the first six years of the 35-year cycle; after that the closure of the *C. inophyllum* canopy prevents such shade-intolerant crops from growing in the understory. Peanut production follows a similar trend; even under an optimistic scenario, its production can only continue until year eight of the rotation. However, honey production is possible from the 6th year to the 35th year of the rotation, unlike other commodities, which can only be cultivated during the early phase of the agroforestry system when *C. inophyllum* trees are still young. As the Net Present Value (NPV) of honey production can likely increase as *C. inophyllum* trees mature and produce more nectar, this particular system of integration could prove to be a highly desirable investment option for farmers in Wonogiri. If a *C. inophyllum*-based system is to have long-term environmental benefits, it should also remain socioeconomically favourable for local farmers in the long term. As *C. inophyllum* is already being cultivated in the study region, there is a positive likelihood that other farmers will adopt such systems (Rahman et al. 2018).

12.4 Biofuel content

12.4.1 Natural stands

Natural stands of *C. inophyllum* in Indonesia are widely distributed across Java as well as West Sumatra, Riau, Jambi, South Sumatra, Lampung, West Kalimantan, Central Kalimantan, Sulawesi, Maluku, West Nusa Tenggara, East Nusa Tenggara and Papua provinces (Bustomi et al. 2008; Leksono et al. 2010, 2014). Local environmental conditions in these regions vary, as shown in Table 4, producing different biofuel yields between locations and populations (Table 5).

Table 4. Environmental conditions in natural stands of *C. Inophyllum*

No.	Population	Geographical Positions	Population type	Altitude (m asl)	Soil texture	Temp. (°C)	Rainfall (mm per year)
1.	Banyuwangi (East Java)	08°26'45"South 114°20'16" East	Natural forest, along the coast	0	Sandy	23–32	1,400
2.	Cilacap (Central Java)	07°41'20" South 109°8'35" East	Natural forest, along the coast	5–8	Loamy clay	23–32	1,000
3.	Ciamis (West Java)	07°45'0.23" South 108°30'8.29" East	Natural forest, along the coast	2–5	Sandy	23–32	3,000
4.	Pandeglang (Banten)	06°08'0" South 105°50'0" East	Natural forest, along the coast	0	Sandy clay	19–32	3,100
5.	Pariaman (West Sumatra)	0°35'39" South 100°06'09" East	Natural forest, along the coast	0	Sandy	23–32	2,000
6.	Ketapang (West Kalimantan)	01°12'52,20"South 109°55'50.52" East	Natural forest, along the coast	0–15	Sandy	25–30	2,000
7.	Sumenep (Madura)	07°04'31.6" South 113°49'50.1" East	Natural forest, along the coast	2–3	Sandy	26–29	900
8.	Dompu (West Nusa Tenggara)	08°17.18'0.2 South 117°59'54.2" East	Natural forest, along the coast	0	Sandy	20–32	500
9.	Selayar (South Sulawesi)	06°09'8.2" South 120°30'51.7" East	Natural forest, hilly areas	9–35	Clayish	21–34	1,700
10.	Yapen (Papua)	01°56'04.1" South 136°21'49.4" East	Natural forest, along the coast	0	Sandy	24–30	1,500

Sources: Leksono et al. 2010, 2011

Table 5. Biofuel content of *C. Inophyllum* in natural stands

No.	Population *C. inophyllum*	Dry seed (kg)	CCO (%)	RCCO (%)
1.	Banyuwangi (East Java)	2.09	42.58	41.63
2.	Cilacap (Central Java)	2.10	40.48	37.24
3.	Ciamis (West Java)	2.00	40.00	39.60
4.	Pandeglang (Banten)	1.81	37.02	36.49
5.	Sumanep (Madura)	6.00	53.17	44.67
6.	Selayar (South Sulawesi)	6.00	50.17	40.67
7.	Padang (West Sumatra)	6.00	50.17	36.00
8.	Ketapang (West Kalimantan)*	6.00	27.50	24.50
9.	Dompu (West Nusa Tenggara)	6.00	58.33	53.00
10.	Yapen (Papua)*	6.00	37.67	22.83

*technical problems occurred during the pressing process

Source: Leksono et al. 2014

The biofuel content of several populations outside Java is higher than those on Java. The highest Crude Calophyllum Oil (CCO) and Refined Crude Calophyllum Oil (RCCO) contents are obtained from populations in Dompu District, West Nusa Tenggara, with values of 58.3% and 53.0%, respectively. Meanwhile, CCO and RCCO yields from other populations range from 50%–53% and 36%–44%, respectively. This high variation in biofuel yield between natural stand populations suggests the necessity for provenance-based selection for better yields (Leksono et al. 2014).

Several physical-chemical properties of *C. inophyllum* biodiesel meet the flash point, cetane index, cloud point, sediment and water content, copper strip corrosion at 3°C–50°C, sulphate ash, sulphur content, phosphor content, acid value, total glycerol, ester alkali, iodine value and Halphen test requirements of Indonesian National Standard SNI 04-7182-2006 for biodiesel. However, several parameters: specific gravity, kinematic viscosity, micro carbon residue, distillation at 90% volume and free glycerol do not meet this standard. This indicates the importance of improving the processing of CCO into biodiesel (Sudrajat and Hendra 2012; Leksono et al. 2014).

12.4.2 Plantations

Table 6 shows the difference between unimproved and improved *C. inophyllum* plantations in terms of biofuel production potential. The table also shows that biofuel content from the provenance seed stand in Wonogiri produced 11%–14%, 7%–9% and 7%–8% higher CCO, RCCO, and biodiesel yield, respectively, compared to the original seed source in Gunung Kidul. Soil layer thickness and soil fertility are different in the two locations (Leksono et al. 2015, 2017), and genotype and environment interaction also affects biofuel yield (Burdon 1977).

Table 6. Biofuel content of *C. Inophyllum* plantations

No.	Location	CCO (%)	RCCO (%)	Biodiesel (%)
1.	Watusipat, Gunung Kidul, Yogyakarta (Unimproved seeds, as origin source population of provenance seed stand (PSS)	50.00–50.12	46.85–47.52	28.95–29.24
2.	Wonogiri, Central Java (Improved seed – PSS 2014)	61.92–64.79	54.34–56.56	35.84–36.72
3.	Wonogiri, Central Java (Improved seed – PSS 2015)	60.16–69.07	52.46–53.63	36.10–36.74
4.	Wonogiri, Central Java (Improved seed – PSS 2016)	53.56–58.00	36.89–43.56	24.67–32.00

Sources: Leksono et al. 2014, 2017

Gunung Kidul Research Station has a *C. inophyllum* plantation of two hectares, established in 1950 by the Forest Research and Development Agency (Forda), Bogor, to rehabilitate the land. Through the natural regeneration process, the forest stand was expected to become denser with seed productivity falling with time. The stand was expected to produce seed until it reached 50 years old. The provenance seed stand in Wonogiri was established using selected trees planted with a wider spacing (5 m x 5 m) for easier harvesting (Leksono et al. 2015). Trees were selected using a breeding programme to improve forest product productivity (Burdon and Shelbourne 1972; Namkoong et al. 1988).

Reliance on raw materials from unselected natural or planted stands and the lack of improved *C. inophyllum* seed likely result in inconsistencies in *C. inophyllum* oil production and quality. As strategic breeding is one possible solution for enhancing *C. inophyllum* oil quality (Leksono and Widyatmoko 2010), a programme was started to identify initial stand potential and land properties within and between six *C. inophyllum* populations from Java (Leksono et al. 2010) and six from outside Java (Leksono et al. 2011). The establishment of provenance seed stands using genetic material for high biofuel content was the next step. The best clone in terms of high seed productivity, biofuel content, and General Combining Ability (GCA) would then be selected and reproduced through vegetative propagation in order to shorten its reproductive cycle (Leksono and Widyatmoko 2010). As with most breeding programmes, the main objective was to maximize the gain per unit time as efficiently as possible, and to provide a broad genetic base for continued progress over many generations (Zobel and Talbert 1984).

The oil content of the provenance seed stands fell in 2016 compared to the previous year (Table 6). However, CCO content (53.56%–58.00%) remained higher than in the original population (50.00%–50.12%). RCCO content and biodiesel yield that year ranged from 36.89% to 43.56% and 24.67% to 32.00%, respectively (Leksono et al. 2017). Biofuel yields could have varied at different times because the seeds were collected from open cross-pollinated fruits. Biofuel yields can also vary depending on population origin, time of collection, age of tree and processing equipment used (Sudrajat et al. 2010; Hasnam 2011).

Oil content fell by approximately 14%–16% when CCO was processed into RCCO, indicating high conversion of resin/gum in kernels (dried seed). Seeds of young fruits usually contain more gum than those of ripe fruits. RCCO is a product of degumming CCO, a process that separates oil and gum (resin). Gum content is a characteristic of *C. inophyllum* seeds. Gum, a by-product of biodiesel, contains coumarin, which has potential uses in the pharmaceuticals and cosmetics industries. Oil content verification from the provenance seed stand in Wonogiri will continue periodically to determine oil content increment stability in the provenance seed stand from the origin population in Gunung Kidul (Leksono et al. 2017).

12.5 Waste utilization and use of by-products

Several processes are involved in producing biodiesel from *C. inophyllum*: fruit crushing, seed pressing, degumming, esterification, transesterification, washing and drying (Bustomi et al. 2008; Leksono et al. 2014). Solid waste (seed shells, seed dregs) and liquid waste (resin, acid grease and glycerol) are produced in biodiesel processing, as shown in Table 7.

Table 7. By-products from biodiesel processing of *C. Inophyllum* collected from seven regions in Indonesia

No.	Population	Fruit weight (kg)	Seed shell (%)	Dry seed (kg)	Seed dregs (%)	Resin (%)	Acid grease (%)	Glycerol (%)
1.	Gunung Kidul (Yogyakarta)	20	57.5	7.3	23.34	3.15	8.22	5.21
2.	Sumanep (Madura)	20	55.0	6.0	26.67	8.50	9.83	10.67
3.	Selayar (South Sulawesi)	20	60.0	6.0	26.67	9.50	6.33	0.23
4.	Padang (West Sumatra)	20	55.0	6.0	16.67	14.17	10.83	3.00
5.	Ketapang (West Kalimantan)	20	60.0	6.0	53.33	3.00	2.67	1.67
6.	Dompu (WNT)	20	55.0	6.0	28.33	5.33	9.00	7.00
7.	Yapen (Papua)	20	57.5	6.0	26.67	14.83	2.67	1.33

Source: Leksono et al. 2017

Seed shells are the first and heaviest waste produced from various plants in biodiesel processing. Shell wastes range from 25% to 60% depending on species, e.g., *Jatropha* (25%), candlenut (30%), *Calophyllum* (55%-60%) and palm oil (60%) (Sudrajat et al. 2004; Purwanto 2011; Lempang et al. 2012; Leksono et al. 2017). Shells can be utilized in making charcoal, and can be used to make charcoal briquettes, activated charcoal and liquid smoke (Leksono et al. 2017). Compressed charcoal briquettes are considered an alternative renewable energy source due to their low environmental impact and because they make use of a waste by-product. Liquid smoke can be used to preserve food, e.g., fresh fish, meat and noodles, and is also used in rubber processing (Darmadji 2002; Gumanti 2006). *Calophyllum* shells produce high-quality liquid smoke when treated at 500°C for five hours. The yield is 45.3%, with density of 1.009 g ml-1, a phenol value of 3.95%, and an acid value of 9.47%. Safety tests have indicated that *C. inophyllum* shell liquid smoke is not toxic and is safe for food (Wibowo 2012).

C. inophyllum seed dregs are the waste left over from seed pressing. They contain high levels of rough protein (21.67%– 23.59%), which can be used as a mixer in ruminant feed (Leksono et al. 2014; Leksono et al. 2017). Another use of *C. inophyllum* seed dregs is for plant compost. Solid waste from *C. inophyllum* seeds contains the following nutrients: 2.6% total N (very high), 52.2% organic C (very high), 0.14% total P (very low), 1.03% total K (very low) and a C:N ratio of 20:26 (very high). This nutrient content meets the Indonesian National Standard (SNI) for compost (Kirana 2016).

Another by-product of biodiesel production from *C. inophyllum* seeds providing additional value is coumarin resin, a potential raw material for pharmaceuticals and cosmetics. The coumarin content produced from *C. inophyllum* seeds from various islands in Indonesia is quite high, with an average value ranging from 0.26% to 0.41%, but if after being processed into CCO, the coumarin content is higher, it can reach 1,33% (Leksono et al. 2014). Thus, *C. inophyllum* seeds have significant potential for pharmaceutical and cosmetics production (Leksono et al. 2017).

Glycerol is a by-product of the transesterification process (Leksono et al. 2017). Successful transesterification is signified by the separation of the methyl ester (biodiesel) and glycerol layers after the reaction time. Glycerol has a multitude of uses in the pharmaceutical, cosmetics and food industries. It can be sold as it is or purified for use in other industries, such as soap or detergent production (Naomi et al. 2013).

12.6 Conclusion

C. inophyllum grows in a wide range of environmental conditions. Young trees can grow up to one metre per year for the first few years, and at a slower rate in subsequent years. The species is highly adaptable, as shown by survival rates exceeding 60% when planted on marginal land in Gunung Kidul District, and 95% on mineral land in Wonogiri. Applying *C. inophyllum*-based agroforestry systems combining annual crops, such as maize, cassava, peanuts, soybeans and fodder grass, could increase farmers' incomes by IDR 217.25 million annually in Gunung Kidul, while in Wonogiri, combining *C. inophyllum* with rice, peanut, maize and honey production would provide higher earnings. *C. inophyllum* is a potential bioenergy species with CCO and RCCO content ranging from 36%–58.30% and 17%–33.8%, respectively. Improved stands could increase oil content by 11%–14% (CCO), 7%–9% (RCCO) and 7%–8% (biodiesel). In addition, the industrial waste and by-products of processing *C. inophyllum* for biodiesel could be utilized to produce products including charcoal, briquettes, liquid smoke, animal feed, compost, soaps, pharmaceuticals and cosmetics. This would increase the economic value of *C. inophyllum* cultivation, and simultaneously reduce environmental pollution.

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