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Innovative and flexible single screw press for the oil extraction of *Calophyllum* seeds

Yuli Setyo Indartono [1,2], *Heriawan Heriawan* [1], *Ika Amalia Kartika* [3,4]*

[1]*Department of Mechanical Engineering, Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung, Bandung, Indonesia*
[2]*Research Center on New and Renewable Energy, Institut Teknologi Bandung, Bandung, Indonesia*
[3]*Department of Agroindustrial Technology, Faculty of Agricultural Technology, Institut Pertanian Bogor University, Bogor, Indonesia*
[4]*Department of Bioenergy and Chemurgy Engineering, Faculty of Industrial Technology, Institut Teknologi Bandung, Bandung, Indonesia*
**Corresponding author: ikaamalia@ipb.ac.id*

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Abstract: The oil extraction of *Calophyllum* seeds using a conventional single screw press leads to an inferior yield and is perceived to be less efficient as well as difficult to operate. An innovative and flexible single screw press was, therefore, designed and investigated in this study to solve these problems. Moreover, the effects of the seeds' moisture content, pressing temperature and seeds' feed rate on the oil yield and quality were identified to determine the optimal oil extraction performance from the *Calophyllum* seeds. The study found that the seeds' moisture content, pressing temperature and seeds' feed rate generally affected the oil yield. The yield indeed improved as the pressing temperature and the seeds' feed rate increased respectively from 45 to 75°C and 1.5 to 5 kg·h^{-1}. The oil yield also ameliorated as the seeds' moisture content rose from 1.7 to 12.8%, but it was optimal when the seeds' moisture content was 5.5%. The best oil yield of 80.6% was, thus, obtained with the seeds' moisture content of 5.5%, a pressing temperature of 75°C and the seeds' feed rate of 5 kg per hour. Although the quality of the crude oil was poor with a high viscosity (≥ 94 mm^2·s^{-1}) and high acid value (≥ 48 mg KOH/g), its density, saponification and iodine values were acceptable. After the oil refining process by degumming and neutralisation, its quality improved and met the Indonesian Biofuel Standards, except for its viscosity.

Keywords: Biofuel; *Calophyllum*; mechanical extraction; degumming; neutralisation

The *Calophyllum* plant produces non-edible and oily seeds. The oil content of these seeds can reach up to 75% (dry matter basis) (Amalia Kartika et al. 2018), and this is higher than that of the jatropha seeds (40–60%) (Amalia Kartika et al. 2016). In Indonesia, this plant is growing widely on the coastal areas and can produce seeds of approximately 20 t·ha^{-1}·yr^{-1} (Leksono et al. 2014). Furthermore, its production is higher than the jatropha (5 t·ha^{-1}·yr^{-1}) and palm (6 t·ha^{-1}·yr^{-1}). *Calophyllum* oil has the potential to be used as a biofuel due to its excellent properties (Jain et al. 2018). It was also widely used as a lamp oil, in traditional medicine, and in cosmetics (Dweck, Meadows 2002).

Calophyllum oil is frequently extracted by a single screw press (Jahirul et al. 2013; Fadhlullah et al. 2015) but the extracted oil is inferior in both quantity (less than 35% based on the dried seed mass) and quality. Because of its high viscosity and low fluidity, extraction of the *calophyllum* oil using a single screw press is challenging and less flexible. In addition, the frictions between the material con-

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veyed along the screw and the barrel wall mainly determine the efficacy of the oil extraction (Evon et al. 2013). A single screw press can, thus, consume a lot of energy, and due to its low capacity of mixing it can cause the material to overheat.

On the other hand, the application of a twin-screw press configured with different screw types has been proven to successfully extract oil from various oilseeds with a high quantity and quality of the oil yield (Kartika et al. 2005, 2006; Amalia Kartika et al. 2010; Evon et al. 2013). The higher flexibility and productivity of this twin-screw press compared to the single screw press had a positive impact on the oil extraction efficiency and its economic feasibility. Furthermore, the oil yield could be ameliorated by optimising the operating conditions, namely the seeds' feed rate, screw rotation speed and pressing temperature. It could also be enhanced by conditioning the seeds' moisture content (Orhevba et al. 2013). In fact, the latter has an important effect on the strength needed to rupture the seeds (Udoh et al. 2017).

An innovative and flexible single screw press configured with different screw types as in the twin-screw press was designed and investigated comprehensively in this study to extract oil from the *Calophyllum* seeds. The influence of the seeds' moisture content, pressing temperature and the seeds' feed rate in the oil recovery and quality was further identified to determine the optimal oil extraction performance.

MATERIAL AND METHODS

Material. The C*alophyllum* seeds were obtained from Cilacap Regency, Central Java Province, while the chemicals were supplied by Merck and Sigma-Aldrich (Indonesia).

Oil extraction. The C*alophyllum* seeds were dried at the temperature of 60°C for 20–200 h to obtain the seeds whose moisture content was 1.2–15%. The seed particle sizes were reduced to approximately 5 mm using a blender (Philips, China), and they were packed with aluminium foil to maintain their moisture content. Each pack contained 400 g of the sample.

The single screw press used in this study was designed as a modular barrel (Fig. 1) and configured with 3 screw types, namely the transport (T), forward (F) and idle screws (I) (Fig. 2). Each screw had a different pitch length, and its configuration along the screw press could be flexibly modified to optimise the oil extraction of the *Calophyllum* seeds. The forward screw possessed 2 different pitch lengths; i.e., 10 mm (F10) and 16 mm (F16) with a screw length of 10 cm. The transport screw had a length of 10 cm with a pitch length of 66 mm (T66). Both screws were installed in the screw press to provide the conveying and pumping actions. The idle screw was an oval-shaped one 34 mm in diameter (I34) and 2 cm in length. It was positioned to adjust the grinding action. A filtration module with 627 holes was placed on the fifth module to separate the oil from the cake. The screw profile tested in this study was T66/F16/I34/I34/I34/I34/I34/F16/F10 (Fig. 1). It was deemed to be the most optimal screw profile obtained from the previous study (Heriawan et al. 2018) since this screw profile could build-up pressure in the screw press to around 1,400–1,500 kgf·cm^{-2}.

The oil extraction process was conducted at a screw rotation speed of 25 rpm, the seeds' feed rate of 1.5–5 kg·h^{-1} and a pressing temperature of 45–75°C. The extracted oil was then filtered using a vacuum filter to eliminate the impurities, and the filtered oil was weighed. The oil yield was, thus, calculated based by Eq. (1):

$$\text{Oil yield}\left(\%\right) = \frac{m_o}{m_s} \times 100 \quad (1)$$

where: m_o – the filtered oil mass; m_s – the oil mass contained in the dried seeds according to their moisture content

All the experiments in this study were repeated two times, and the data obtained were shown in the mean.

Oil purification. To improve its quality in order to meet the biofuel standards, the extracted oil was purified by degumming and neutralisation processes. First, the oil was heated up to 70°C, and a 20% phosphoric acid solution was added into it with the ratio of 1:5 (v/w). This mixture was then stirred for 25 minutes. Moreover, an NaOH solution with concentration of 18°Be (12.69 wt.%) was added into this mixture and it was stirred for 10–15 minutes. The mixture was cooled to room temperature and left for a few days to precipitate the solids. The separated oil was then washed with warm water of 60–70°C until it reached a neutral pH, and it was heated at 105°C for 1 h to evaporate the water.

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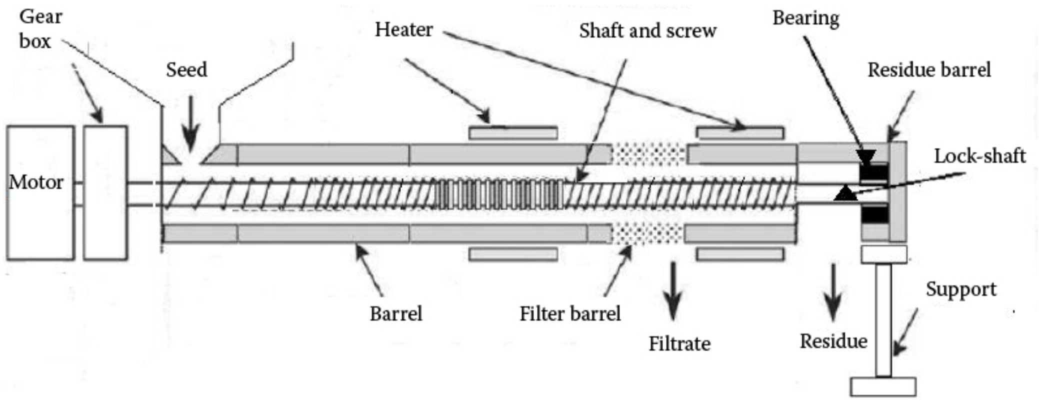

Fig. 1. The module and screw configuration of the single screw press used for the oil extraction from the *Calophyllum* seeds

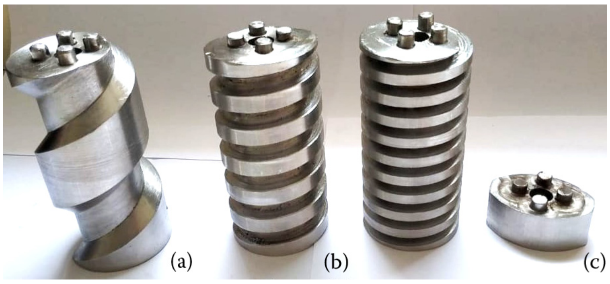

Fig. 2. The screw types used for the oil extraction from the *Calophyllum* seeds: transport screw (a), forward screw (b), idle screw (c)

Analytical methods. The moisture and the ash contents of the *Calophyllum* seeds were analysed using the method of SNI 01-2891-1992, whereas their oil, protein and total carbohydrate contents were respectively analysed using the method (18-8-5/MU/SMM-SIG Weilbull), the method (18-8-31/MU/SMM-SIG Kjeltec) and the method (18-8-9/MU/SMM-SIG). The quality of the extracted and purified oil was examined by the analyses of the saponification value (AOCS Ca 14–56), the acid value (AOCS Cd 3–63), the iodine value (AOCS Cd 1–25), density (ASTM D 1298) and kinematic viscosity (ASTM D 445).

RESULTS AND DISCUSSION

Based on the results of the proximate analysis (Table 1), the *Calophyllum* seeds contained 53.3% (dry matter basis) of the oil for 27.6% moisture content. They also contained ash, proteins and carbohydrates. In this study, the moisture content of the seeds was varied to optimise the oil extraction process. This variation in the moisture content of the seeds had caused their oil content to vary too (Table 2). The oil content of the seeds surged as their moisture content fell. The low moisture content of the seeds may lead to the increase in the mass transfer of triglycerides (Kanda et al. 2013). In addition, heating the seeds to reduce their moisture content during drying can rupture the oil cells and coagulate the proteins. Furthermore, it can facilitate the oil to diffuse out of the cells. Hence, reducing the seeds' moisture content in oil the extraction of the *Calophyllum* seeds using a screw press could significantly improve the oil yield and the extraction efficiency (Fadhlullah et al. 2015). At a low moisture content, the pressure in the screw press may expand due to the increased seed rigidity. The higher the pressure build-up in the screw press the larger the volume of oil is extracted.

In the mechanical oil extraction using a screw press, the pressing efficiency is significantly affected by the oilseeds' moisture content (Uitterhaegen, Evon 2017). The reason is that water possesses a substantial effect on the rheological material properties, and it can play a role as a lubricant. Besides, this augmentation in the pressing efficiency is due to the expanded pressure in the screw press with the increasing rigidity of the seeds at a low mois-

Table 1. The *Calophyllum* seeds properties

Parameter	Value (wt.)
Moisture content	27.6
Oil content (db)	53.3
Protein content (db)	6.7
Ash content (db)	1.7
Carbohydrate content (db)	10.8

db – dry basis; wt. – weight

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Table 2. The oil content of the *Calophyllum* seeds at different moisture contents

Target moisture content (wt%)	Actual moisture content (wt%)	Oil content (wt., db)
1.2	1.7	71.2
5.0	5.5	70.3
10.0	10.3	65.5
15.0	12.8	59.6

db – dry basis; wt. – weight

ture content. The pressing efficiency is also influenced by the operating conditions where the latter can enhance the pressure build-up in the screw press with a rise in the seed feed rate and a drop in the screw rotation speed (Kartika et al. 2005, 2006). The effect of pressure on the pressing efficiency can, thus, be investigated by applying various seeds' moisture contents and operating conditions during the oil extraction process by the screw press, as well as different screw configurations.

In this study, for all the pressing temperatures tested, the oil yield increased as the seeds' moisture content declined (Fig. 3). At the pressing temperature of 45°C, the oil yield climbed continually as the seeds' moisture content plummeted from 12.8 to 1.7%, while at the pressing temperature of 60–75°C it increased only when the seeds' moisture content decreased from 12.8 to 5.5%. It was found that the moisture content of less than 5.5% did not improve the oil yield. In a similar vein, such a phenomenon was also observed by other researchers (Jahirul et al. 2013; Bhuiya et al. 2015; Fadhlullah et al. 2015).

In addition to the properties of the raw materials, the operating conditions of the screw press also have a significant influence on determining the optimal moisture content for the effective oil pressing (Uitterhaegen, Evon 2017). They consist of the seeds' feed rate, the screw rotation speed and temperature, as well as the screw profile, which can determine the degree of filling of the screw press, the pressure build-up, and the friction. For all the seeds' moisture contents tested, the oil extracted at the pressing temperature of 60 and 75°C was higher in quantity than those of 45°C, and the oil yield improved as the pressing temperature increased (Fig. 3). This higher increase in the oil yield was clearly observed at the seeds' moisture content of 5.5–12.8%. At a low pressing temperature, the improvement in the oil yield was likely due to the increasing pressure in the screw press with the inclining rigidity of the seeds at a low moisture content. At a high pressing temperature, this improvement was not only caused by this but also by the decreased oil viscosity and protein coagulation, which facilitated the release of the oil through the fibrous matrix. In this study, the optimum moisture content for the oil extraction from the *Calophyllum* seeds was, thus, 5.5%. This value was inferior than that obtained by Jahirul et al. (2013) and Bhuiya et al. (2015) (5.5% versus 15%), but superior than that obtained by Fadhlullah et al. (2015) (5.5% versus 1.2%). The application of this moderate moisture content in the mechanical extraction of the *Calophyllum* oil may facilitate a production cost reduction, the feasible storage handling of the seeds, and the seeds quality maintenance. Drying the seeds until their moisture content reached lower than 5.5% will boost the energy consumption in the oil production of the *Calophyllum* seeds. Furthermore, the low moisture content of the seeds will extend their shelf life and prevent them from hydrolysis caused by enzymes.

At a pressing temperature of 60–75°C, the oil extraction yield obtained in this study (38.3–40.8% based on the dried seed mass) for approximately the

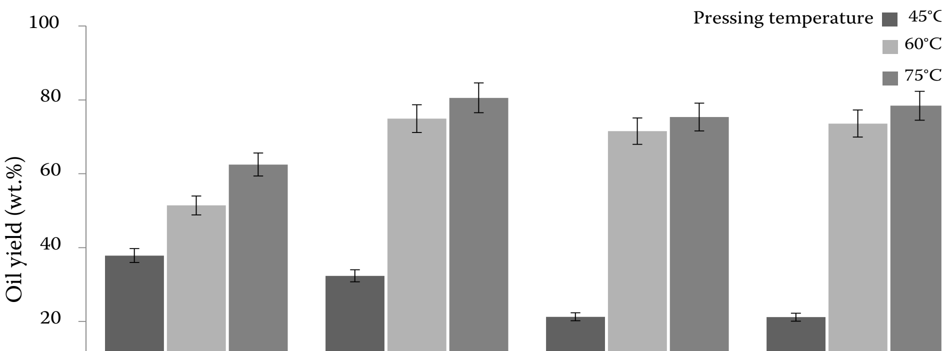

Fig 3. The oil extraction yield as a function of the seeds' moisture content at the different pressing temperatures (the seeds' feed rate of 5 kg·h^{-1} and screw rotation speed of 25 rpm)

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same moisture content of the *Calophyllum* seeds (13–15%) was higher than that obtained by Jahirul et al. (2013) (less than 30%) and Bhuiya et al. (2015) (± 36%). Likewise, for the seeds' moisture content of < 2%, the result was also superior to the oil yield obtained by Fadhlullah et al. (2015) (36.0–43.8% based on dried seeds mass vs 33.4%). The application of the screw press designed in this study showed better performance for the oil extraction of the *Calophyllum* seeds than that of the conventional screw press. Moreover, it was more flexible in its module configuration, and the screw profile was easily modified. The variety of the screw configured along the single screw press improved its effectiveness. The transport and forward screws assure that the pertinent material is conveyed and pumped (Uitterhaegen, Evon 2017). In this study, these screws were positioned on the module section of the feed and compression. The combination of F16 and F10 screws positioned on the filtration module allowed for the effective oil expressions of the *Calophyllum* seeds while the idle screws positioned before the filtration module allowed for the material to be crushed and the oil cells to rupture.

The influence of the seeds' feed rate in the oil extraction performance was investigated at the seeds' moisture content of 1.7%, a screw rotation speed of 25 rpm and a pressing temperature of 60–75°C, and its result showed an oil yield improvement as the seeds' feed rate soared from 1.5 to 5 $kg\cdot h^{-1}$ for each pressing temperature tested (Fig. 4). This improvement in the oil yield was due to an increase in the degree of filling inside the screw press, which increased the pressure inside the screw press. Besides, it was due to the longer residence time of the material inside the screw press, so the pressing time elevated as the seeds' feed rate escalated. However, when too high of the seeds' feed rate is applied, this leads to a blockage in the filtration module by the solid particles, and this will cause clogging of the screw press owing to the backflow of seeds to the feeder. The application of the seeds' feed rate of > 5 kg per h in this study caused the screw press to clog. With this condition, an enhancement of the screw rotation speed should be applied to reduce the degree of the filling inside the screw press. For the mechanical oil extraction with a superior pressing efficiency, Dufaure et al. (1999) reported that the applied ratio of the seeds' feed rate to the screw rotation speed (CF) should be between 0.05 and 0.20 $kg\cdot h^{-1}\cdot rpm^{-1}$ to avoid the machine clogging. In this study, the CF used for the *calophyllum* seed oil extraction was 0.06–0.20 $kg\cdot h^{-1}\cdot rpm^{-1}$ too, and the application of an appropriate CF combined with high pressing temperature should improve the oil yield even better. The oil extracted at the pressing temperature of 75°C was better than that of 60°C for each of the seeds' feed rate tested.

The crude *calophyllum* oil extracted in this study presented a tolerable quality for each extraction condition tested. It had a density of £ 0.91 $g\cdot cm^{-3}$, a saponification value of 204–209 mg $KOH\cdot g^{-1}$ and an iodine value of £ 101 g I_2 per 100 g (Table 3), but its viscosity and acid value were very high, i.e., > 94 $mm^2\cdot s^{-1}$ and > 48 mg $KOH\cdot g^{-1}$, respectively. The quality of the crude oil decreased as the seeds' moisture content and the pressing temperature increased, principally for the viscosity and acid value. These two parameters grew as the seeds' moisture content and pressing temperature rose, while the other parameters were relatively stable. It may be due to an increase in the crude oil's resin content. A previous study (Amalia Kartika et al. 2018) reported that the *Calophyllum*

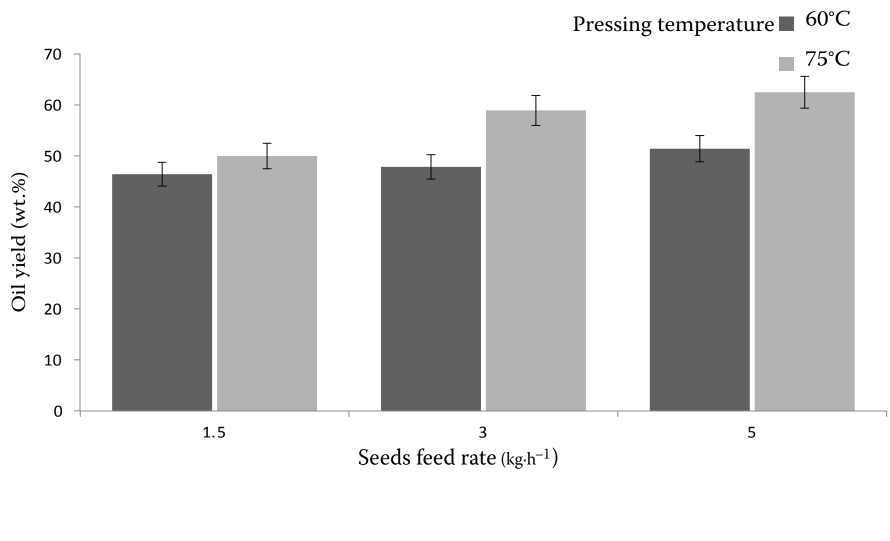

Fig 4. The oil extraction yield as a function of the seeds' feed rate at the different pressing temperatures (the seeds' moisture content of 1.7% and screw rotation speed of 25 rpm)

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seeds contained 28.8% of resin (dry matter basis). Therefore, the mechanical extraction using the screw press from the *calophyllum* seeds will extract the oil and also the resin, and the latter will be extracted more at high moisture content of the seeds due to its high polarity. Besides, based on the micrograph of the *Calophyllum* seeds (Amalia Kartika et al. 2018), the resin was present within the cells. Hence, the mechanical extraction at a high pressing temperature will enhance the fluidity and reduce the viscosity of the resin, and it will facilitate its release throughout the fibrous matrix. Furthermore, the resin extracted from the *Calophyllum* seeds is comparable to myrrh (Dweck, Meadows 2002), and its acid value is very high (≥ 160 mg $KOH \cdot g^{-1}$) (Amalia Kartika et al. 2018).

Compared with the results of previous studies (Boucher 2000; Amalia Kartika et al. 2010; Atabani et al. 2013), the quality of the crude oil obtained in this study was not better, i.e., a density of 0.90–0.91 $g \cdot cm^{-3}$ vs 0.93–0.95 $g \cdot cm^{-3}$, a viscosity of 94–111 $mm^2 \cdot s^{-1}$ vs 63–98 $mm^2 \cdot s^{-1}$, an acid value of 54–76 mg $KOH \cdot g^{-1}$ vs 35–54 mg $KOH \cdot g^{-1}$, a saponification value of 204–209 mg $KOH \cdot g^{-1}$ vs 133–137 mg $KOH \cdot g^{-1}$, and an iodine value of 90–101 g I_2/100 g vs 106–108 g I_2/100 g. However, it is important to note that its quality became better after the oil degumming and neutralisation processes, and this met the Indonesian Biofuel Standards (Table 3). The degumming and neutralisation significantly diminished the acid value of the oil from 48–54 mg $KOH \cdot g^{-1}$ to 1 mg $KOH \cdot g^{-1}$ and its viscosity was lessened by about 41%. In addition, both processes also cut down the density from 0.91 $g \cdot cm^{-3}$ to 0.88 $g \cdot cm^{-3}$. These processes removed the impurities from the oil, in particular the resin and free fatty acids. The presence of the resin in the *Calophyllum* oil caused its viscosity and density to rise whereas the free fatty acid enhanced its acid value (Amalia Kartika et al. 2010). For the application of *Calophyllum* oil as a biofuel, preheating at 90–100°C should be applied to reduce its viscosity before it enters the combustion chamber.

CONCLUSION

The mechanical *Calophyllu*m oil extraction had been successfully conducted in this study using an innovative single screw press designed with flexible modules and different screw types. This screw press was able to extract the oil well using a screw profile consisting of idle (I34) screws in the crushing zone and forward (F16 and F10) screws in the pressing zone. Moreover, the oil yield improved systematically at a high pressing temperature and the seeds' feed rate, and at a low moisture content. The best oil yield of 80.6% was produced at the pressing temperature of 75°C and the seeds' feed rate of 5 $kg \cdot h^{-1}$, while the optimal moisture content for the oil extraction from the *Calophyllum* seeds was 5.5%. In addition, the quality of the crude oil was tolerable, and it improved when the seeds' moisture content and the pressing temperature were low. Lastly, the oil purification process through degumming and neutralisation improved its quality to meet the Indonesian Biofuel Standards.

Table 3. The physiochemical properties of the extracted *Calophyllum* oil

	Moisture content (%)	Pressing temp. (°C)	Density ($g \cdot cm^{-3}$)*	Viscosity ($mm^2 \cdot s^{-1}$)*	Acid value (mg $KOH \cdot g^{-1}$)	Saponification value (mg $KOH \cdot g^{-1}$)	I value (g I per 100 g)
Before degumming and neutralisation	12.8	45	0.909	110.6	76.3	205.4	98.1
	10.3	45	0.906	105.9	58.8	204.9	100.9
	5.5	45	0.904	101.7	51.5	204.2	94.1
	1.7	45	0.905	94.1	48.5	205.2	96.8
	1.7	60	0.905	103.2	54.2	207.4	93.0
	1.7	75	0.905	107.0	67.8	208.7	90.1
After degumming and neutralisation	1.7	45	0.879	55.3	0.980	203.9	84.0
	1.7	60	0.879	60.8	0.999	203.7	86.7
Indonesian biofuel standard			0.90–0.92 (50°C)	max. 36 (50°C)	max. 2	180–265	max. 115

*temperature 25°C

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References

Amalia Kartika I., Fathiyah S., Desrial, Purwanto Y.A. (2010): Refining of *calophyllum* oil and its application as biofuel. Jurnal Teknologi Industri Pertanian, 20: 122–129.

Amalia Kartika I., Pontalier P.Y., Rigal L. (2010): Twin-screw extruder for oil processing of sunflower seeds: Thermo-mechanical pressing and solvent extraction in a single step. Industrial Crops and Products, 32: 297–304.

Amalia Kartika I., Evon P., Cerny M., Suparno O., Hermwan D., Ariono D., Rigal L. (2016): Simultaneous solvent extraction and transesterification of jatropha oil for biodiesel production, and potential application of the obtained cakes for binderless particleboard. Fuel, 181: 870–877.

Amalia Kartika I., Cerny M., Vandenbossche V., Rigal L., Sablayrolles C., Vialle C, Suparno O., Ariono D., Evon Ph. (2018): Direct *Calophyllum* oil extraction and resin separation with a binary solvent of *n*-hexane and methanol mixture. Fuel, 221: 159–164.

Atabani A.E., Anjum B.I., Mahlia T.M.I, Masjuki H.H., Chong W.T., Lee K.T. (2013): Investigation of physical and chemical properties of potential edible and non-edible feedstock for biodiesel production. Renewable and Sustainable Energy Reviews, 21: 749–755.

Bhuiya M.M.K., Rasul M.G., Khan M.M.K., Ashwath N., Azad A.K., Mofijur M. (2015): Optimisation of oil extraction process from Australian native beauty leaf seed (*Calophyllum inophyllum*). Energy Procedia, 75: 56–61.

Boucher C. (2000): *Calophyllum* oil extracted at ambient temperature has UV protecting, antiradical, antioxidant, antiaging and therapeutic properties. FR9907772A.

Dufaure C., Leyris J., Rigal L., Mouloungui Z. (1999): A twin-screw extruder for oil extraction: I. direct expression of oleic sunflower seeds. Journal of the American Oil Chemists' Society, 76: 1073–1079.

Dweck A.C., Meadows T. (2002): Tamanu (*Calophyllum inophyllum*) – The African, Asian, Polynesian and Pacific panacea. International Journal of Cosmetic Science, 24: 1–8.

Evon Ph., Amalia Kartika I., Cerny M., Rigal L. (2013): Extraction of oil from jatropha seeds using a twin-screw extruder: feasibility study. Industrial Crops and Products, 47: 33–42.

Fadhlullah M., Widiyanto S.N.B., Elvi Restiawaty E. (2015): The potential of nyamplung (*Calophyllum inophyllum* L.) seed oil as biodiesel feedstock: effect of seed moisture content and particle size on oil yield. Energy Procedia, 68: 177–185.

Heriawan, Indartono Y.S., Kartika I.A. (2018): Optimization of mechanical oil extraction process of Nyamplung seeds (*Calophyllum inophyllum* L.) by flexible single screw extruder. AIP Conference Proceedings, 1984: 1–10.

Jahirul M.I., Brown R.J., Senadeera W., Ashwath N., Laing C., Leski-Taylor J., Rasul M.G. (2013): Optimisation of bio-oil extraction process from beauty leaf (*Calophyllum inophyllum*) oil seed as a second generation biodiesel source. Procedia Engineering, 56: 619–624.

Jain M., Chandrakant U., Orsat V., Raghavan V. (2018): A review on assessment of biodiesel production methodologies from *Calophyllum inophyllum* seed oil. Industrial Crops and Products, 114: 28–44.

Kanda H., Li P., Yoshimura T., Okuda S. (2013): Wet extraction of hydrocarbons from *Botryococcus braunii* by dimethyl ether as compared with dry extraction by hexane. Fuel, 105: 535–539.

Kartika I.A., Pontalier P.Y., Rigal L. (2005): Oil extraction of oleic sunflower seeds by twin screw extruder: influence of screw configuration and operating conditions. Industrial Crops and Products, 22: 207–222.

Kartika I.A., Pontalier P.Y., Rigal L. (2006): Extraction of sunflower oil by twin screw extruder: screw configuration and operating condition effects. Bioresource Technology, 97: 2302–2310.

Leksono B., Hendrati R.L., Windyarini E., Trimaria Hasnah T. (2014): Variation in biofuel potential of twelve *Calophyllum inophyllum* populations in Indonesia. Indonesian Journal of Forestry Research, 1: 127–138.

Orhevba B.A., Chukwu O., Osunde Z.D., Ogwuagwu V. (2013): Influence of moisture content on the yield of mechanically expressed neem seed kernel oil. Natural and Applied Sciences, 4: 252–257.

Udoh J., Olayanju T., Dairo O., Alonge A. (2017): Effect of moisture content on the mechanical and oil properties of soursop seeds. Chemical Engineering Transactions, 58: 361–366.

Uitterhaegen E., Evon Ph. (2017): Twin-screw extrusion technology for vegetable oil extraction: a review. Journal of Food Engineering, 212: 190–200.

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