2nd International Conference on Sustainable Energy Engineering and Application, ICSEEA 2014

The potential of nyamplung (*Calophyllum inophyllum* L.) seed oil as biodiesel feedstock: effect of seed moisture content and particle size on oil yield

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**Abstract**

Nyamplung (*Calophyllum inophyllum* L.) is one of the most potential plants for biodiesel feedstock because of its high oil content. Mechanical extraction using screw press is one method to get oil from nyamplung seed. Result of the extraction is affected by the seed’s condition, such as moisture content and particle size. The paper presents experimental results that estimate the vegetable oil production potential of *C. inophyllum*. The results show the effect of *C. inophyllum* seed moisture content and particle size on oil yield, and the characteristics of *C. inophyllum* oil. The seed moisture contents used in this experiment are 0%, 1.2%, and 20%, whereas the average seed particle size used are 0.81, 2.90, and 8.60 mm. The *C. inophyllum* fruits were obtained from Cipatujah Sub-district, Tasikmalaya Regency. The methods used include fruit and seed preparation, seed moisture content and particle size conditioning, mechanical extraction, oil characteristics analysis, and *C. inophyllum* oil production potential calculation. The optimum seed moisture content to obtain high oil yield is 1.2% which yields 33.39% oil, while the optimum seed particle size to obtain high oil yield is 8.60 mm which yields 33.46% oil. The bigger the particle size will affect on higher oil yield. From this research, it can be concluded that the trees in Cipatujah have potential to produce *C. inophyllum* oil up to 5.13 L/tree/year. *C. inophyllum* oil yield is affected by seed moisture content and particle size, and it has characteristics that support its utilization as biodiesel feedstock.

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Peer-review under responsibility of Scientific Committee of ICSEEA 2014

**Keywords:** *Calophyllum inophyllum* L. seed; biodiesel feedstock; mechanical extraction; moisture content; particle size; oil yield

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1. Introduction

Here the decrease of fossil fuel deposit and negative impacts of its utilization on environment has increased the alternative fuel development, including biodiesel. Biodiesel is a renewable, environment friendly, and non-toxic fuel. It does not contain sulphurous and aromatic compounds[1].

Nyamplung (*Calophyllum inophyllum* L.) is one of many plants in Indonesia which has big potential to become biodiesel feedstock because of its high seed oil content[2]. The seed oil content in *C. inophyllum* is in range of 40-75% (dry weight basis)[3,4,5], higher than Jatropha seed oil content (40-60%) and rubber seed oil content (40-50%)[3]. The productivity of *C. inophyllum* seed is also high. It can reach 20 tonnes seed/hectare, higher than rubber seed productivity (2 tonnes seed/hectare) and Jatropha seed productivity (5 tonnes seed/hectare)[6]. Besides, *C. inophyllum* is a non-edible plant, so its utilization as biodiesel feedstock will not intercept with food provision[7].

Despite of its high seed oil content, the yield and quality of *C. inophyllum* oil are effected by its extraction method. The common oil extraction method used in industry, especially home industry, is mechanical extraction. It has more economical benefits than the other oil extraction methods. The oil yield from mechanical extraction can be effected by the seed condition, such as seed moisture content and particle size[8]. The optimum seed moisture content and particle size can be applied in the society, so they can increase the *C. inophyllum* oil yield. Therefore, it is important to study the *C. inophyllum* seed moisture content and particle size conditioning which can optimize *C. inophyllum* oil yield. The objectives of this paper are to estimate *C. inophyllum* oil production potential, to investigate the effect of *C. inophyllum* seed moisture content and particle size on oil yield, and to analyze the characteristics of *C. inophyllum* oil.

2. Materials and methods

2.1. Nyamplung (*Calophylluminophyllum*) fruit sample

Nyamplung (*C. inophyllum*) fruits Fig. 1 were obtained from CipatujahSud-district, Tasikmalaya Regency on March 2014. The source of the fruits was 30-40 years old *C. inophyllum* trees[9]. The fruits obtained had yellowish brown skin colour and were collected from the ground, which indicated that they were physiologically matured[10]. The fruits had 1-3 cm diameter.

![Fig.1. C. inophyllum fruits](image)

2.2. Analysis of *C. inophyllum* physiological condition

*C. inophyllum* physiological condition analysis was carried out by using literature data, including tree’s age, geographical, temperature, light, and soil condition.
2.3. C. inophyllum seed moisture content and particle size conditioning for extraction unit feed

*C. inophyllum* fruits were sun dried for 4-6 hours[11], weighed using analytical or common balance, and then manually peeled. The *C. inophyllum* seeds obtained were then weighed to calculate the seed yield[12].

Effect of seed moisture content was investigated using *C. inophyllum* seeds which have dried using oven at 65°C[13]. Seed moisture content variations used in this paper, which were 20%, 1.2%, and 0%, were obtained from 3, 8, and 14 days of drying. The seeds were then milled to reach 0-20 mm particle size using OM-AGC 15 milling machine at Bioengineering Laboratory, Bandung Institute of Technology (ITB), Jatinangor.

Effect of seed particle size was investigated using *C. inophyllum* seeds which have dried using oven at 65°C for 21 days (seed moisture content 0%). The variations of average seed particle size, which were 8.60, 2.90, and 0.81 mm, were obtained from milling and sieving process.

2.4. C. inophyllum oil mechanical extraction

Mechanical extraction was carried out using Piteba simple screw press at Bioengineering Laboratory, Bandung Institute of Technology (ITB), Jatinangor. The amount of *C. inophyllum* seeds as feed for extraction process was 100-400 gram. *C. inophyllum* oil obtained then separated from the waste using centrifuge at 4000 rpm for 30 minutes[14]. After that, calculation of oil yield and process efficiency was carried out[15].

2.5. Analysis of C. inophyllum oil’s characteristics

Analysis of *C. inophyllum* oil characteristics included density test[16], viscosity test[17], oil water content test[14], burning test, and calorie test. The characteristics of *C. inophyllum* oil then compared to the characteristics of virgin coconut oil (VCO) which was also tested.

2.6. Calculation of C. inophyllum oil production potential

Estimation of *C. inophyllum* oil production potential was calculated using Equation 1.

\[
\text{Vegetable oil production potential (L/tree/year) = } \frac{C_{\text{fruits}} \times Y_{\text{seeds}} \times m_{\text{dry}} \times Y_{\text{oil}}}{m_{\text{wet}} \times \rho_{\text{oil}}} \tag{1}
\]

The area needed for *C. inophyllum* plantation was calculated using Equation 2.

\[
\text{Plantation area (hectare) = } \frac{E}{H_{\text{oil}} \times \rho_{\text{oil}} \times C_{\text{oil}} \times \Sigma_{\text{trees/hectare}}} \tag{2}
\]

In Equation 1, \(C_{\text{fruits}}\) is *C. inophyllum* fruits production capacity (kg/tree/year), \(Y_{\text{seeds}}\) is *C. inophyllum* seeds yield (%), \(m_{\text{dry}}\) is *C. inophyllum* seeds mass after drying (kg), \(m_{\text{wet}}\) is *C. inophyllum* seeds mass before drying (kg), \(Y_{\text{oil}}\) is oil yield (%), and \(\rho_{\text{oil}}\) is oil density (kg/L). In Equation 2, \(E\) is energy consumption (kJ/year), \(H_{\text{oil}}\) is oil calorie value (kJ/kg), \(\rho_{\text{oil}}\) is oil density (kg/L), \(C_{\text{oil}}\) is oil production capacity (L/tree/year), and \(\Sigma_{\text{trees/hectare}}\) is amount of trees that can be planted in 1 hectare area (tree/hectare).

3. Results and discussion

3.1. Effect of C. inophyllum oil seed moisture content on oil yield

From Fig. 2, extraction process with seed moisture content of 1.2% yields the highest oil, 33.39% (dry weight basis) with the highest extraction efficiency, 58.07%. It is followed by the extraction with seed moisture content of 0% that yields 28.87% (dry weight basis) oil, with extraction efficiency of 50.21%. Extraction with seed moisture content of 20% yields the lowest oil, 15.56% (dry weight basis), with the lowest extraction efficiency, 27.05%. The
result shows that *C. inophyllum* oil yield effected by *C. inophyllum* seed moisture content. It also shows that extraction of *C. inophyllum* seed with lower moisture content tends to yield higher oil. This is similar with the result of Orhevba et al. (2013)[18] and Farsie and Singh (1985) in Orhevba et al. (2013)[18], by using neem seed and sunflower seed respectively. It is inferred that this phenomena caused by the drying process. Drying can stimulate the activity of membrane and cell wall hydrolyzing enzymes, and also gives heat to the seed that can denaturalyze the protein structure inside *C. inophyllum* seed cell membrane. Hydrolyzing and denaturalyzing process can break the cell wall and membrane structure, so the possibility of oil to be extracted gets higher [15].

![Fig.2. The effect of C. inophyllum seed moisture content on oil yield.](image)

Fig. 2 also shows that the oil yield tends to increase from extraction with *C. inophyllum* seed moisture content of 0% to 1.2%, but it decreases when the seed moisture content is 20%. This can be resulted because there is a possible optimum seed moisture content range to be used in extraction process. According to Ferchau (2010), Owolafare et al. (2003), and Ogunsina et al. (2008) in Orhevba et al. (2013)[18], the optimum seed moisture content for extraction with screw press is 7-8%.

As a comparison, another research data about *C. inophyllum* oil extraction using screw press is also used. According to Jahirul et al. (2013)[12], *C. inophyllum* oil extraction using screw press yields 26% (dry weight basis) oil. The result is different with this paper’s result. This can be resulted by two factors, which are different fruit sources and process condition. The *C. inophyllum* fruits used in this paper were collected from Cipatujah, Indonesia, while Jahirul et al. (2013)[12] used fruits from northern Australia. Both fruit sources certainly have different environment condition. Different environment condition, such as climate, temperature, and rainfall, can effect the oil production inside *C. inophyllum* seed[15]. Then, the configuration of screw press that was used in this paper and by Jahirul et al. (2013)[12] is also different. Different configuration, such as pressing pressure, compression ratio, and pressing rate, can also effect oil yield from the seed[12].

Table 1 shows the characteristics of *C. inophyllum* oil obtained from extraction with seed moisture content conditioning. The oil characteristic tests were carried out to validate that *C. inophyllum* oil obtained in this paper is indeed a vegetable oil. Besides, it also used to analyze *C. inophyllum* oil potential as biodiesel feedstock.
Density of *C. inophyllum* oil obtained from seed moisture content conditioning lies inside the range of literature value, which is 0.906-0.944 g/mL[3,5,11]. Density of *C. inophyllum* oil also lies above virgin coconut oil’s density value. This shows that *C. inophyllum* oil is heavier than virgin coconut oil. *C. inophyllum* oil has not been further processed, so it probably still contains polluter, such as resin.

Viscosity of *C. inophyllum* oil obtained from seed moisture content conditioning, with the exception of seed moisture content of 20%, lies inside the range of literature value, which is 28.27-56.7 cP[3,5,11]. It is predicted that seed with moisture content of 20% still contains relatively high resin, so it produces oil with high viscosity value. According to Hathurusingha (2012)[15], *C. inophyllum* seed contains resin up to 20% (wet weight basis). Seed with moisture content of 1.2% and 0% probably has relatively low resin content, because the drying process has made the resin discharge from the seed, and then it sticks to the drying container wall. The viscosity value of *C. inophyllum* oil also higher than virgin coconut oil. It likely happens because *C. inophyllum* oil has not been further processed, so it still contains polluter and make it more viscous.

The viscosity of *C. inophyllum* oil is categorized as relatively high, because the viscosity value of vegetable oil that accepted to become biodiesel is in range of 1.63-5.16 cP[15]. The utilization of high viscosity oil as diesel machine fuel will result bad atomization process. It will generate carbon deposit and sticky oil ring inside the machine, and also make the lubricant oil harder because of high viscosity oil contamination. Therefore, the the *C. inophyllum* oil should be further processed to lower its viscosity before it is used as biodiesel feedstock. One of the process that can lower the viscosity of *C. inophyllum* oil is transesterification[1].

Water content of *C. inophyllum* oil obtained from seed moisture content conditioning lies inside the literature value range, which is 0.25-0.41%[3]. Water content of *C. inophyllum* oil is lower than virgin coconut oil. Low water content will decrease the possibility of oil oxidation, so the quality of oil will be preserved. Low water content will also lower the oil’s corrosivity to metal, and lower the possibility of oil’s contamination by microorganism, which can degrade the oil[15]. Besides, it can also lower the emission caused by water burning[3].

Fire colour of the burning of *C. inophyllum* oil obtained from seed moisture content conditioning is reddish orange. As comparison, fire colour of virgin coconut oil burning is orange. Fire colour represents the qualitative energy value of burning[19]. By observing on fire colour, it is presumed that *C. inophyllum* oil has lower energy value than virgin coconut oil. This estimation shows that *C. inophyllum* oil has lower performance than virgin coconut oil if it will be further processed as biodiesel feedstock. But, the validation of the real energy value should be done by using calorie test.

Smoke colour of the burning of *C. inophyllum* oil obtained from seed moisture content conditioning is black. This shows that the oil contains polluter. If *C. inophyllum* oil will be used as biodiesel feedstock, it should be further processed to remove the polluter content from the oil. On the other side, virgin coconut oil burning produces white smoke. This probably done because virgin coconut used is a vegetable oil that has been further processed, so it contains low polluter.

The calorific value of *C. inophyllum* oil obtained from seed moisture content conditioning lies inside the literature calorie value range, which is 32,500-39,200 J/g[5,11]. As comparison, virgin coconut oil’s calor value is 36,777.90 g/L, kerosene’s is 37,620 J/g[20], and cooking oil’s is 36,882.35 J/g. *C. inophyllum* oil calorie value is in the range

<table>
<thead>
<tr>
<th>Characteristics</th>
<th><em>C. inophyllum</em> oil</th>
<th>Commercial Virgin Coconut Oil (VicoBagoes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed moisture content 0%</td>
<td>0.907</td>
<td>0.896</td>
</tr>
<tr>
<td>Seed moisture content 1.2%</td>
<td>0.910</td>
<td>NA</td>
</tr>
<tr>
<td>Seed moisture content 20%</td>
<td>0.927</td>
<td>22</td>
</tr>
<tr>
<td>Literature [3,5,11]</td>
<td>0.906-0.944</td>
<td>0.25-0.41%</td>
</tr>
<tr>
<td>Density at 27°C (g/mL)</td>
<td>37,206.60</td>
<td>37,340.06</td>
</tr>
<tr>
<td>Viscosity at 27°C (cP)</td>
<td>37,340.06</td>
<td>37,482.41</td>
</tr>
<tr>
<td>Water content of oil (%)</td>
<td>Black</td>
<td>Black</td>
</tr>
<tr>
<td>Fire colour</td>
<td>Reddish orange</td>
<td>Reddish orange</td>
</tr>
<tr>
<td>Smoke colour</td>
<td>Black</td>
<td>Black</td>
</tr>
<tr>
<td>Calorie value (J/g)</td>
<td>37,482.41</td>
<td>36,777.90</td>
</tr>
</tbody>
</table>

Table 1. The characteristics of *C. inophyllum* oil obtained from seed moisture content conditioning and virgin coconut oil
of virgin coconut oil, kerosene, and cooking oil calory value. This result shows that *C. inophyllum* oil can be considered as biodiesel feedstock.

As an overall, *C. inophyllum* oil obtained from seed moisture content conditioning can be used as biodiesel feedstock. However, the seed with moisture content of 1.2% is more considerable to be used than the other two variations, because it produces the highest oil yield. Furthermore, to use it as biodiesel feedstock, the oil should also be further processed to lower its viscosity value.

### 3.2. Effect of *C. inophyllum* oil seed particle size on oil yield

![Fig.3. The effect of *C. inophyllum* seed particle size on oil yield.](image)

Fig. 3 shows that *C. inophyllum* seed extraction with seed particle size of 8.60 mm yields the highest oil, 33.46% (dry weight basis), and highest extraction efficiency, 58.19%. It is followed by *C. inophyllum* seed extraction with seed particle size of 2.90 mm that yields 25.95% (dry weight basis) oil, with extraction efficiency of 45.13%. The *C. inophyllum* seed extraction with seed particle size of 0.81 mm yield the lowest oil, 21.88% (dry weight basis), with the lowest extraction efficiency, 38.05%. This result shows that oil yield is effected by *C. inophyllum* seed particle size. The oil yield tends to increase with the decrease of *C. inophyllum* seed particle size used. Shahidi (2005) in Arlene and Ariono (2013)[14] has studied that vegetable oil yield can be increased by decreasing the seed size. The seed size decreasing process can break the seed cell wall, and also help the heat comes inside the cell easier to help breaking the cell wall. This will increase the possibility to extract the oil. Also, according to Shahidi (2005)[21] seed size decreasing process can widen the contact area between screw press and the seed. This process can also increase the possibility to extract the oil. Increasing the oil yield by decreasing the seed particle size has been proven by using soy and cotton seed. The result from Fig. 3 has inverse tendency with the result from Arlene and Ariono (2013)[14]. It is presumed that decreasing seed size will not always increase the oil yield, because there is a seed size range limit which will optimize the oil yield. This result can also be happened because the design of the screw press does not suitable with seed particle size variations used. This shows that the screw press design can also effect the extraction performance[13].

Table 2 shows the characteristics of *C. inophyllum* oil obtained from seed particle size conditioning with comparison to commercial virgin coconut oil.
Table 2. The characteristics of C. inophyllum oil obtained from seed particle size conditioning and virgin coconut oil

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>C. inophyllum oil</th>
<th>Commercial Virgin Coconut Oil (VicoBagoes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seed particle size 0.81 mm</td>
<td>Seed particle size 2.90 mm</td>
</tr>
<tr>
<td>Density at 27°C (g/mL)</td>
<td>0.915</td>
<td>0.913</td>
</tr>
<tr>
<td>Viscosity at 27°C (cP)</td>
<td>38</td>
<td>53</td>
</tr>
<tr>
<td>Water content of oil (%)</td>
<td>0.39</td>
<td>0.4</td>
</tr>
<tr>
<td>Fire colour</td>
<td>Reddish orange</td>
<td>Reddish orange</td>
</tr>
<tr>
<td>Smoke colour</td>
<td>Black</td>
<td>Black</td>
</tr>
<tr>
<td>Calorie value (J/g)</td>
<td>38,001.04</td>
<td>37,592.26</td>
</tr>
</tbody>
</table>

The density of C. inophyllum oil obtained from seed particle size conditioning lies within the literature density value [3,5,11]. It also higher than virgin coconut oil density. This phenomena has been discussed in the previous section.

The viscosity of C. inophyllum oil obtained from seed particle size conditioning lies inside the literature viscosity value [3,5,11], with exception of the oil obtained from seed with particle size of 8.60 mm. It is also higher than the viscosity of virgin coconut oil. This has been discussed in the previous section.

The water content of C. inophyllum oil obtained from seed particle size conditioning, with exception of seed with particle size of 8.60 mm, lies inside the literature value [3]. But, all of them are lower than virgin coconut oil water content. The explanation of this has been discussed in the previous section.

The burning of C. inophyllum oil obtained from seed particle size conditioning generate reddish orange fire and black smoke. This result and its explanation are relatively similar with the result and explanation of C. inophyllum oil obtained from seed moisture content conditioning.

The calorie value of C. inophyllum oil obtained from seed particle size conditioning lies inside the literature calorie value range [5,11]. This result and its explanation has been also discussed in the previous section.

It can be said that the seed with particle size of 8.60 mm is more considerable to be chosen as biodiesel feedstock, because it produces the highest oil yield. However, the oil must be further processed to gain less viscous oil.

3.3. Estimation of C. inophyllum oil production potential as biodiesel feedstock

Cipatujah Sub-district was chosen as basis of calculation because it was where the C. inophyllum fruit sample used in this experiment obtained from. Furthermore, Cipatujah is also the habitat of C. inophyllum and has environment condition that supports its growth and oil production. According to Hamdan (2010) [22], the area of Cipatujah Sub-district is 24,465.45 hectares.

C. inophyllum fruit production capacity data used in this calculation is 60 kg/tree/year [3]. This data is based on C. inophyllum trees that live in Batukaras, Pangandaran Regency. The fruit production capacity of C. inophyllum trees that live in Cipatujah is assumed to be similar with C. inophyllum trees that live in Pangandaran, because Cipatujah and Pangandaran are still in the same area of East Priangan. The other data used in estimation calculation are obtained from this research and provided at Table 3.

This paper results that have been discussed in the previous section can be used as a reference for Cipatujah people. In this case, they can use C. inophyllum seed moisture content and seed particle size that can optimize the oil production. If the process condition in this research used by Cipatujah people to extract the C. inophyllum oil, it is estimated that the trees in Cipatujah have potential to produce C. inophyllum oil up to 5.13 L/tree/year (Fig. 4). This data can be used for the next research and development about C. inophyllum oil production. As an example is for the development of C. inophyllum plantation to fulfill the Cipatujah energy demand.
Table 3. Seed yield, dry and wet seed mass ratio, oil yield, and C. inophyllum oil density data

<table>
<thead>
<tr>
<th>Data</th>
<th>Seed moisture content conditioning</th>
<th>Seed particle size conditioning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Seed yield (%)</td>
<td>37.82</td>
<td>36.64</td>
</tr>
<tr>
<td>Dry seed mass and wet seed mass ratio (g/g)</td>
<td>0.6</td>
<td>0.62</td>
</tr>
<tr>
<td>Oil yield (% dry weight basis)</td>
<td>28.99</td>
<td>33.5</td>
</tr>
<tr>
<td>C. inophyllum oil density (kg/L)</td>
<td>0.907</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Fig. 4. Estimation of C. inophyllum oil production in Cipatujah Sub-district

If it is assumed that Cipatujah consumed 64.5 millions MJ/year fuel[23], and there are 400 trees that can be planted inside one hectare of area[3], the area needed to make C. inophyllum plantation is around 920.6 hectares. Based on Cipatujah's area, the development of C. inophyllum plantation is feasible to be done. However, further study about its management should be carried out, so it will not give negative impacts on the society and environment.

As discussed before, C. inophyllum oil has characteristics that supports its utilization as biodiesel feedstock. Biodiesel can be used as fuel in Cipatujah people daily activity, such as in farming and fishery. It also can be used as the fuel for local electricity generator. Besides of biodiesel, people of Cipatujah can also make C. inophyllum oil as biokerosene feedstock. Biokerosene can be used as fuel for cooking activity, or as a fuel for lighting equipment.

The development of C. inophyllum as biofuel feedstock is also supported by its own added value. C. inophyllum tree has been generally used as coast revitalization plant, windbreak plant, and shield against abrasion. Moreover, all of C. inophyllum parts have value. For instance, its wood can be utilized as material for boat construction and high value carving. It also contains numerous chemicals that can be used as cosmetic and pharmaceutical products[3].

The utilization of biofuel that obtained from local natural resources, like C. inophyllum in Cipatujah, hopefully will create energy independent society without dependency on fossil based fuel. It also hopefully will decrease the negative impacts that resulted from fossil based fuel utilization.
4. Conclusion

Drawing from the experimental results presented in this paper, it is concluded that *C. inophyllum* seed is highly potential for vegetable oil production. Cipatujah Sub-district could produce *C. inophyllum* oil up to 5.13 L/tree/year. Our results show that the extraction of *C. inophyllum* seed with moisture content of 1.2% yields the highest oil yield of 33.39% (dry weight basis), whereas extraction of *C. inophyllum* seed with particle size of 8.60 mm yields the highest oil yield of 33.46% (dry weight basis). *C. inophyllum* oil obtained under the experimental conditions has characteristics that supports its utilization as biodiesel feedstock. These results can also serve as a practical reference to local farmers and bio-oil producers. To better help the local communities, a further research could be carried out to investigate the effects of wider climate conditions of the Cipatujah region on the production of *C. inophyllum* oil.

References