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RESEARCH ARTICLE

The election of edible and non edible crop for biodiesel feedstock in Indonesia with AHP-BCR and GC analysis

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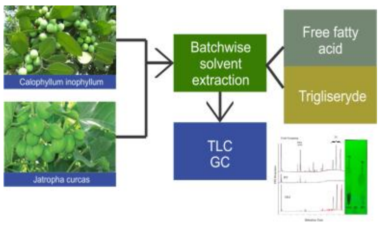
Graphical abstract



Abstract

The increasing trend of domestic fuel consumption that is not followed by domestic fuel production creating problem for Indonesian government to fulfill the shortage of fuel consumption. The high dependence of Indonesian government on imported fuel creates some problem due to the large subsidy that must be given as a result of the increasing oil prices. This makes the development of biofuel important, especially biodiesel with an abundant raw material in Indonesia. In this work, the best alternative and the composition of raw materials for making biodiesel were investigated by using Gas Chromatographic (GC) and Analytic Hierarchy Process (AHP) - benefit-cost ratio (BCR). With GC analysis, it is expected to know the content of triglyceride (TG) and free fatty acid (FFA) content in crude oil for each alternative raw material. While the AHP-BCR analysis is expected to know the best alternative to raw materials for biodiesel production. The alternative raw materials that are selected namely *Calophyllum inophyllum* and *Jatropha curcas*. The selection of alternative raw material based on oil content, yield, and raw material cost. The criteria used for benefit hierarchy structure are economic, social, raw material availability, environment and technical. As for the hierarchy of cost structure, the criteria are the price of raw materials, opportunity cost, processing cost, environmental cost, and social cost. The present study clearly proved that *C. inophyllum* and *Jatropha curcas* oil potentially become the best alternative material for biodiesel production. The result shown from benefit-cost ratio were almost identical (*jatropha curcas*, 1.01 and *C.Inophyllum*, 1). From GC analysis, *C. Inophyllum* became the potential alternative material because it has the biggest oil content for crude (75.99%) and after purification (94.24%)

Keywords: AHP, biodiesel, benefit-cost ratio, GC analysis, TLC analysis

INTRODUCTION

Increasing population, expanding urbanization causes the increasing of food and energy demand in the world. This increasing demand of food and energy is not followed by the the reserves of fossil fuel that have a declining trend. The other problem is the uses of fossil oil creating the environmental concerns. So, it is very important to develop the future energy to fulfill the demand of energy and environmental friendly. One of the future energy is biodiesel. In recent studies, raw materials of biodiesel are edible oil such as palm oil, sunflower oil, and rapeseed. The utilization of edible oil to fulfill energy demand induces problems like the sustainability of the implementation due to its competition with land, water and food (Kansedo et al., 2009; Santacesaria et al., 2012). The other reasons, it also could cause food shortage especially in growing countries and environmental problems due to the use of available arable land to produce oil crops (Atabani et al., 2013).

Recently, the use of vegetable oils falls into two applications namely food industry, and industrial uses, including biodiesel. FAO (2013) reported that the use of edible oil is mostly for food, and biodiesel markets are far behind. Thus, the rapidly growing demand for edible oils has been triggered by the food market rather than industrial or biodiesel market. In the food industry, edible oil is used for human consumption, such as baking, margarine, and frying fats or shortening (Alston et al., 2002). Using non-edible oil for biodiesel has one major weakness. The yields and quality of biodiesel produced are less than edible oil. Both edible and non-edible oil has its advantages and disadvantages. Thus, the choosing of the most appropriate source amongst them is very important based on the optimal benefits.

In such condition, multi-criterion decision making (MCDM) methods are widely used. One of the method is The Analytic Hierarchy Process (AHP) that was introduced by Saaty (1986). This method is an effective tool for dealing with such complex decision-making problems and could endorse the decision maker to set priorities and make the greatest decision. The AHP helps to capture both subjective and objective aspects of a decision by sinking complex decisions to a series of pairwise comparisons and then synthesizing the results. The essence of AHP is that it simplifies a complex decision by decomposing the problem into a hierarchy of 'criteria' or sub-problems to be analyzed individually. One of the criteria observed is technical. This criteria was used a gases chromatography method to measure triglyceride (TG) and free fatty acid (FFA) contents in the feedstocks. TG and FFA coumpounds were a key parameter to make biodiesel production (refined vegetable oil) from many feedstock (aparamarta et al., 2016).

The purpose of this research is to select and prioritize the best alternative to raw materials for biodiesel production. The alternative raw materials that are selected namely *Calophyllum inophyllum* and *jatropha curcas*. The selection of alternative raw materials was based on the oil content, yield and feedstock price (Gui, et al, 2008). They became the important factor to resolve the suitability of a crop as the raw material for biodiesel production. The reason is oil crops with higher oil yield could decrease the production cost. Generally, the cost of raw materials achieve about 70–80% of the total production cost of biodiesel (Gui et al., 2008). The criteria used for benefit hierarchy structure are economic, social, raw material availability, environment and technical. As for the hierarchy of cost structure is the price of raw materials, opportunity cost, processing cost, environmental cost, and social cost. This criteria of hierarchy benefit and cost were based on the improvement of the previous works. Ilham and Nime (2019) was evaluted the best priotity of biodiesel feedstock with FFA content, oil yield, and plant avaibility as the criterias of AHP methods. The other criterias are government policy, plant productivity and surplus production of raw material (Hambali et al., 2016).

EXPERIMENTAL

Materials

C. inophyllum and *Jatropha curcas* oil was bought from Koperasi Jarak Tani Lestari (Klaten, Indonesia) and some forest (Wonosobo, Central Java and Cirebon, West Java, Indonesia). Thin-layer chromatography (TLC) aluminum plates were obtained from Merck (Darmstadt, Germany). Standard triolein, tripalmitin and fatty acids were purchased from Sigma Chemical Company (St. Louis, MO). All reagents and solvents were either analytical-grade or HPLC-grade were obtained from commercial sources.

Extraction of nonpolar lipids fraction (NPLF) from crude *C. inophyllum* and *Jatropha curcas* oils (Single-stage solvent extraction)

The single stage extraction was explained by Aparamarta et al., (2016). Nonpolar solvents (petroleum ether) and polar solvent (methanol) were applied in this work. The ratio of mixture solvent (non polar and polar solvent) of 3:1 was used in this work. The result of this extraction have 2 layers namely non polar lipid fraction (NPLF) and polar lipid fraction (PLF). NPLF, such as hydrocarbons and TG, were extracted by nonpolar solvents in the upper layer. The extract was separated and concentrated to give the NPLF. The polar extract was designated as the polar lipids fraction (PLF). The NPLF and PLF were then analyzed using high temperature gas chromatography (HT-GC) and thin layer chromatography (TLC).

Multistage solvent extraction (Batchwise eight-stage extraction)

Multistage solvent extraction with 8 stages was described by aparamarta et al., (2018). Stirred batchwise method was used in this work. The result of NPLF fraction in the earlier step was extracted using polar solvent (methanol) at room temperature. The adding of polar solvent in the NPLF fraction was done in eight stages to get a higher content of TG. The polar solvent extracts (1−8 stage fractions) were collected and concentrated to give the PLF. Afterward, the NPLF and PLF were analyzed using HT-GC and TLC.

Thin layer chromatography (TLC) analysis

TLC as qualitative analysis was applied to the sample as defined by Gunawan et al. (2008). TLC paper that has been colored by the sample was immersed in a mobile phase of hexane: ethyl acetate: acetic acid at 90: 10: 1 (v/v/v).

High temperature gas chromatography (HT-GC) analysis

Components in *C. inophyllum* seed oil, such as FFA, TG, and other compounds were identified using pure standard solution as defined by Aparamarta et al. (2018). Quantitative analysis of the sample was calculated on a Shimadzu GC-2010 gas chromatograph (Kyoto, Japan), equipped with a flame ionization detector. Separations were carried out on a DB-5HT (5%-phenyl) methylpolysiloxane nonpolar column (Phenomenex, USA).

Analytic hierarchy process-benefit cost ratio (AHP-BCR) analysis

Crude of alternative raw material was extracted and tested with gas chromatography (GC) to measure the content of TG and FFA in the crude *C. Inophyllum* oil. The result of this analysis is used as primary data to be input into economic and technical criteria in benefit hierarchy of AHP analysis.

In this work, Expert Choice 11 was applied to get the finest goal from decision-making problems. It creates a model that can help the human frame which have logic, experience, knowledge and sense factors to optimized in a systematic process (Shean, 2012). This model has 3 layers; the first layer is criteria. It has 4 criteria namely economy, social, raw material availability, environmental and technical for hierarchy benefit and raw material cost, opportunity cost, operating cost, social cost and environmental cost of hierarchy cost. The second layer is sub-criteria. It has machine efficiency, material saving, energy saving, selling power, pro-growth, pro job, pro-poor, reserve, productivity, location, reduced emission, the impact for human health, increased TG and decreased FFA for hierarchy benefit. For hierarchy cost, it has two sub-criteria namely purchased cost and transportation cost

RESULTS AND DISCUSSION

Raw material is key point to implement biodiesel production in Indonesia. Generally, the cost of raw materials reach about 70–80% of the total biodiesel production cost (Kusdiana and Saka, 2002; Demirbas, 2003; Du et al, 2004; Gui et al., 2008). For this reason, yield and oil content become the important factors to decide the suitability of a crop as a raw material for biodiesel production. These factors is the key to reduce the biodiesel production cost (Gui et al., 2008). The biggest component in oil content is TG (Aparamarta et al., 2016). This compound is the key component to make a higher yield in the biodiesel production. The other key component is FFA. This compound composition in the oil should be below than 3% for alkaline-catalyzed transesterification (Ribeiro et al., 2011) The source of edible and non-edible oil can be seen on table I.

Table 1 The non edible and edible source for biodiesel feedstock.

Feedstock	Source	Oil Content (Wt%)	Yield (Kg oil/ha)	Cetane Number	Reference
Non edible oil					
C. inophyllum	Seed	40-73	4680	57	Singh, 2010
Croton tiglium	Seed	30-45	-	-	Azam et al, 2005
Cuphea	Seed	20-38	900	-	Berti & Johnson, 2005
Guizotia abyssinica L. (niger)	Seed	50-60	200-300	-	Umerie et a, 2010
Jatropha curcas L.	Seed	20-60	1590	33.7-51	Sahoo et al, 2007
Madhuca indica	Seed	35-50	-	-	Azam et al, 2005
Melia azedarach	Seed	10-45	-	-	Jean, 2011
Edible oil					
Soybean	Seed	18-20	375	-	Langstraat, 1976; Pryde,1980; Hoffmann, 1989
Palm	Kernel	42	5000	-	Atasie and Akinhamnie, 2009
Rapeseed	Seed	41-46	1000	-	Cakmakli and Unal, 1988

Table 1 shows the source of promising edible and non-edible oil. It can be seen on non edible sources, *Jatropha curcas* and *Calophyllum inophyllum* give the highest oil yields with 1590 and 4680 kg oil per hectare respectively. Therefore, *Jatropha curcas* and *Calophyllum inophyllum* have become a promising feedstock to fulfill energy demand. For edible sources, palm oil gives the highest oil yield with 5000 kg oil per hectare, considerably higher than other oils which are only in the range of hundreds to 1000 kg oil per hectare. Therefore, palm oil has become a promising feedstock to fulfill energy demand. *C. inophyllum* and *Jatropa curcas* have one big advantage over palm in that they were nonedible and will not diminish food supply in growing countries (Atabani et al., 2013).

Batchwise solvent extraction (BSE) method was applied in this work. BSE method was used to replace the step in the chemical process of the refined of vegetable oils production, such as degumming, neutralization, and bleaching steps. From the batchwise solvent extraction result, it was separated into two layer namely NPLF and PLF (Aparamarta, 2018). Furthermore, the content of TG and FFA were chosen as the indicator for the effective separation of NPLF from crude *C. inophyllum* seed oil. Crude alternative raw material before and after purification were tested by HT-GC and TLC to see the content and separation of TG and FFA in the crude *C. inophyllum* and *Jatropha curcas* oil. TLC and HT-GC analysis of crude oil, NPLF, and PLF are shown in Figure 1a and 1b. From this figure, it was shown that TG was successfully separated in the NPLF as confirmed by TLC and HT-GC analyses.

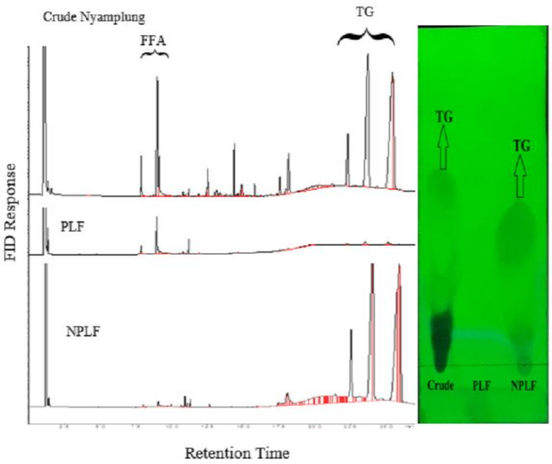


Fig. 1a Result of the (a) HTGC and (b) TLC developed in mobile phase (90:10:1) in the *C.inophyllum* oil

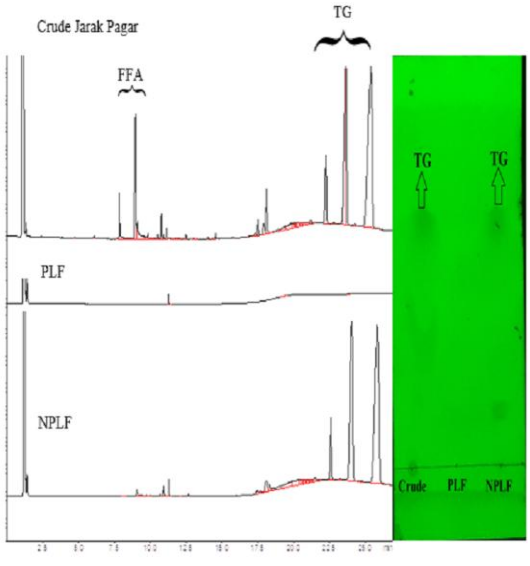


Fig. 1b Result of the (a) HTGC and (b) TLC developed in mobile phase (90:10:1) in the *Jatropha curcas* oil.

The result of this analysis is used as primary data to be input into economic and technical criteria in hierarchy benefit. With GC analysis, it obtained the TG content in *C. inophyllum* and *jatropha curcas* seed as shown in table 2. From this table, it can be seen that the TG content in the crude of *C. Inophyllum* is better than *Jatropha curcas.* TG content after purification also shows a better result on *C. Inophyllum.* The lipid content of *C. inophyllum* seeds reported in this work agrees with the earlier work. Aparamarta et al., (2017) reported that lipids content of *C. inophyllum* seeds was 70.4% .

Table 2 TG content of *C. Inophyllum* and *Jatropha curcas'* seeds.

No	Resources	TG Content (%)	
		Crude	After Purification
1	*Calophyllum inophyllum*	75.99	94.24
2	*Jatropha Curcas*	73.02	93.83

For hierarchy benefit, five types of multifaceted criteria was used namely economic, social, eaw material availability, environment and technical for hierarchy benefit. Five criteria also chosen for hierarchy cost namely the price of raw materials, opportunity cost, processing cost, environmental cost, and social cost. Result of the analysis have been evaluated to determine the best alternative resources for biodiesel production in Indonesian perspective. AHP method was applied in this work to achieve the goal. This method require a procedure for the aggregation of expert opinion using the five selected criteria that are appropriate for biodiesel production. Experts involved in the assessment found that the raw material availability for hierarchy benefit and raw material cost for hierarchy cost are the most important criteria having the priority of 0.387 and 0.419, respectively. This result followed by the priorities of economic, technical, environmental and social as 0.233, 0.215, 0.127, and 0.094, respectively for hierarchy benefit and for hierarchy cost, followed by the priorities of opportunity cost, processing cost, environmental cost and social cost as 0.29, 0.166, 0.077, and 0.049, respectively. This result was aggreed with previous works that surplus production of raw material became the highest criteria for biodiesel feedstocks (Hambali et al. 2015)

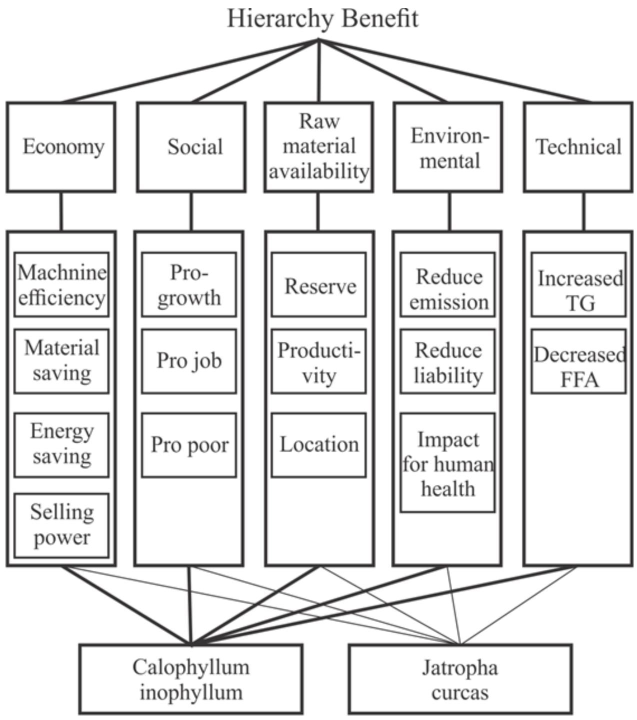


Fig. 2 Model structure of hierarchy benefit.

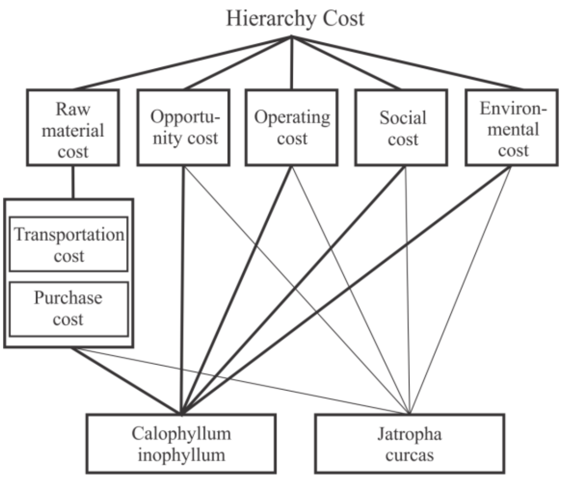


Fig. 3 Model structure of hierarchy cost.

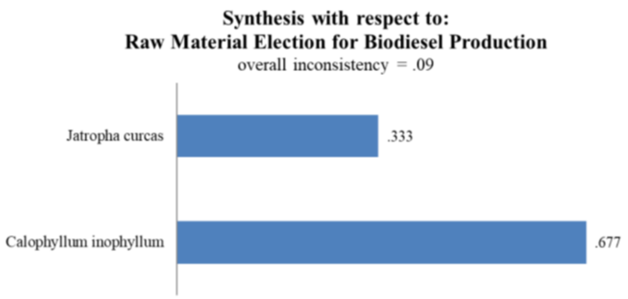


Fig. 4 The goal result of hierarchy benefit.

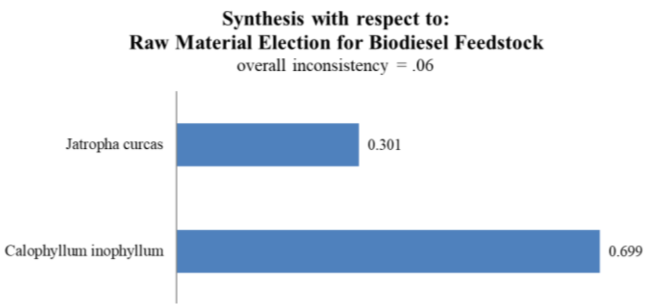


Fig. 5 The goal result of hierarchy cost

From Figure 4 and 5, It can be seen that *Calophyllum inophyllum* has a bigger priority than the *jatropa curcas* for biodiesel production with the priority of 0.699 for hierarchy benefit and 0.667 for hierarchy cost. Followed by the priority of jatropa curcas as 0.301 and 0.333, respectively. The consistency ratio is 0.06 for hierarchy benefit and 0.09 for hierarchy cost, so this data is acceptable (Saaty, 1990 and Saaty,1994-a).

From AHP result, it can be obtain the ratio of benefit and cost. This analyses associated with the acceptace of raw material alternative for biodiesel feedstocks. The alternative will be accept if the the total benefits should be more than the total costs incurred (Boardman et al., 2011). From Benefit cost ratio analysis, it can be seen that *Calophyllum Inophyllum* is potentially became the best alternative material for biodiesel production as can be seen on Table 3. The ratio of benefit and cost were calculated in the *Calophyllum Inophyllum* with ratio of 1.05 and in the *Jatropa Curcas* with ratio of 0.904. This work agreed with previous that the weights of *calophyllum inophyllum* is better than *Jatropa curcas* (Hambali et al,,2016). The other potential of *Calophyllum inopyllum* is the high amount of *oleic acid* content in *Calophyllum inopyllum* (Aparamarta et al.,2018), so its valuable to convert became biodiesel. This content was the biggest parts in the TG (Aparamarta et al.,2018). Kusmiyati and Sugiharto (2010) convert *oleic acid* to became biodiesel with a good quality to be a diesel substitute.

Table 3 AHP result for the election of raw material for biodiesel feedstock.

No	Resources	Hirarchy	Priority	Benefit-Cost Ratio
1	*Calophyllum inophyllum*	Benefit Cost	0.699 0.667	1.05
2	*Jatropa Curcas*	Benefit Cost	0.301 0.333	0.904

CONCLUSION

Calophyllum inophyllum became a potential resource for biodiesel production in Indonesia. It was found from GC analysis and AHP-BCR, *Calophyllum Inophyllum* has bigger TG content (94.24%) and priority (1.05) than Jatropha Curcas. From AHP-BCR analsis, it was found that the most important criterion for the selection of alternative resources on hierarchy benefit is raw material avaibility (0.387). Most important criterion for hierarchy cost is raw material cost (0.419).

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