Pangium edule Reinw: A Promising Non-edible Oil Feedstock for Biodiesel Production

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Abstract Biodiesel production from non-edible feedstocks is currently drawing much attention due to legitimate concerns about the effects of using edible oil for fuel. *Pangium edule* Reinw is a non-edible feedstock. *Pangium* is a tall tree native to the Micronesia, Melanesia and the mangrove swamps of South-East Asia. In this study, biodiesel production and characterization from *P. edule* oil was reported. The seeds were obtained from Bogor, Indonesia. The oil was found to have an acid value of 19.62 mg KOH/g oil. Therefore, a two-step acid–base-catalysed transesterification was used to produce biodiesel. This was followed by evaluating the physical and chemical properties of biodiesel and its blends with diesel. It has been found that the determined properties of *P. edule* methyl ester indicate that the oil can be considered as a future biodiesel source. The most remarkable feature of *P. edule* is its cloud, pour and cold filter plugging points. This biodiesel yielded cloud, pour and cold filter plugging points of −6, −4 and −8 °C, respectively. This indicates the viability of using this biodiesel in cold countries. Therefore, it is suggested that more research should be conducted on *P. edule* for future biodiesel production.

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Abbreviations

CCMO	Crude *Croton megalocarpus* L. oil
CIME	*Calophyllum inophyllum* methyl ester
CMOO	Crude *Moringa oleifera* L. oil
CN	Cetane number
COME	Coconut methyl ester
CPEO	Crude *Pangium edule oil*
CPO	Crude palm oil
CSO	Crude soybean oil
EPEO	Esterified *Pangium edule* oil
IV	Iodine value
JCME	*Jatropha curcas* methyl ester
MOME	*Moringa oleifera* methyl ester
PME	Palm oil methyl ester
PEME	*Pangium edule* methyl ester
SN	Saponification number
SME	Soybean methyl ester

1 Introduction

The fossil fuel burning has caused a tremendous destruction to the environment that led to focussing on the use of biodiesel as a substitute for petroleum-based diesel fuel. The need for looking an alternate to diesel has been further amplified by the threat of diminishing fossil fuel reserves and dependency on foreign energy sources [1–4]. Biodiesel is considered as a sustainable, non-toxic, biodegradable, alternative and clean fuel as it does not contain any sulphur, aromatic hydrocarbons, metals, crude oil residues and contributes a minimal amount of net greenhouse gases to the atmosphere. Therefore, it can be employed in current diesel engines without major modifications of the engines. Biodiesel is defined as mono-alkyl esters of long-chain fatty acids derived from renewable lipid feedstocks, such as vegetables oil or animal fats, and alcohols through transesterification reaction with or without a catalyst. Globally, there are more than 350 oil-bearing crops identified as potential sources for biodiesel production. Historical research has focussed towards biodiesel production from edible oils (such as rapeseed, palm, coconut and sunflower oils) rather than non-edible oils (such as *Jatropha curcas*, *Calophyllum inophyllum* and *Pongamia pinnata* oils) [1–10]. Current statistics suggests that more than 95 % of the world biodiesel is produced from edible oils such as rapeseed (84 %), sunflower oil (13 %), palm oil (1 %), soybean oil and others (2 %). This is because of the fact that edible oils have high yield of biodiesel, and they are easy to be processed (transesterified) due to their low free fatty acids. However, their use raises many concerns such as food versus fuel crisis and major environmental problems such as serious destruction of vital soil resources, deforestation and usage of much of the available arable land. Moreover, in the last ten years the prices of vegetable oil plants have increased dramatically which will affect the economic viability of biodiesel industry [3,11]. Production of biodiesel from non-edible feedstocks such as *Jatropha curcas, Calophyllum inophyllum, Moringa oleifera, Croton megalocarpus, Cerbera odollam, Terminalia (Terminalia belerica Ronx.), Madhuca indica (mahua), Pongamia pinnata (karanja), Guizotia abyssinica L., Hevea brasiliensis (rubber seed) and Azadirachta indica (neem)* is considered as a potential alternative to biodiesel production from edible oils [2,3,8,10,12–18]. *Pangium edule* Reinw oil is one of the possible alternative oil crops for biodiesel production.

1.1 Objective of this Study

To the best of the author's knowledge, no detailed study on the possibility of *P. edule* Reinw oil as a potential non-edible oil feedstock for biodiesel production has been reported in the literature except [19]. Nofiarl et al. [19] have recently reported the production of biodiesel from *P. edule* Reinw. The authors have testified some important properties such as kinematic viscosity, density, acid number, iodine number and saponification number. However, some other important properties such as cloud point, pour point, cold filter plugging point, oxidation stability and calorific value were not presented. Moreover, the crude oil characteristics and fatty acid compositions were not reported in that study. Additionally, the study did not present any properties of *P. edule* Reinw methyl ester and its blends with diesel.

Therefore, the purpose of this work is to produce biodiesel from *P. edule* oil using homogeneous acid catalyst (H_2SO_4) and alkaline catalyst (KOH) followed by a detailed study of physical and chemical properties and fatty acid compositions of the produced biodiesel (PEME). The physical and chemical properties of (PEME–diesel) blends of 5, 10, 15 and 20 % were also studied. The success of this study could yield a promising and massive new raw material for biodiesel production on a large scale. Moreover, a comparison with other feedstocks has been presented in this study for better understanding and evaluation of this feedstock.

1.2 Botanical Description and Distribution of *Pangium edule* (PE)

Pangium edule is a tall tree belongs to *Flacourtiaceae* family. It is known as football fruit, Kepayang and Sis nut. It is a tropical tree that is native to the Micronesia, Melanesia and the mangrove swamps of South-East Asia (Indonesia, Malaysia and Papua New Guinea). Figure 1 shows the distribution of *P. edule* tree around the world and *P. edule* tree, fruit and seeds [20]. The tree can grow very tall (often over 40 m, with a sparse crown spreading perhaps 50 m in diameter). The tree prefers slightly acidic soil with a little shade. The tree has large, glossy, heart-shaped leaves that are conspicuously veined and long-stemmed. The flowers are large and greenish; the sexes are separate. The fruit is oval and about the size of a large husked coconut, brown and rough-surfaced. The exterior colour of the fruits is brown. The outside skin is rough to touch. The inner skin (rind) is pale yellow to white, around an inch thick. The mature fruit is edible; however, the seeds of this tree are poisonous, mostly because of the presence of cyanogenic glucosides [21–23].

2 Materials and Methods

2.1 Materials and Chemicals

The seeds of *P. edule* were supplied from Bogor, Indonesia, through personal communication. Other chemicals such as methanol, H_2SO_4, KOH and Na_2SO_4 were purchased from local market. Qualitative filter paper (filters Fioroni) of 150 mm size was supplied from (Metta Karuna Enterprise, Malaysia).

2.2 Crude Oil Extraction

The kernels of the *P. edule* fruits were obtained manually and cleaned before being dried overnight in an oven at 353 K. A moderate temperature for the drying of the *P. edule* kernels

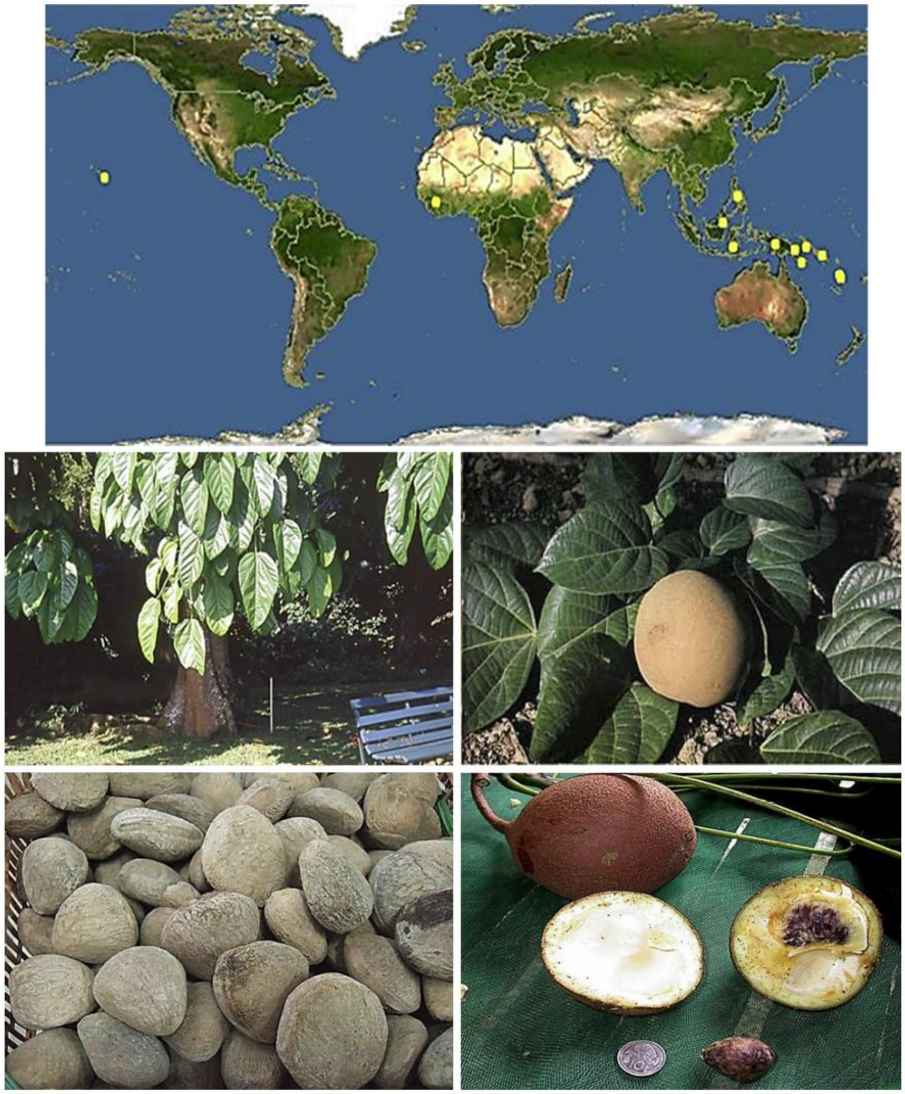

Fig. 1 Distribution of *P. edule* around the world and *P. edule* tree, fruit and seeds [20]

was used to prevent possible decomposition or oxidation of the kernels at higher temperature (>373 K) at which the properties of the extracted oil could be affected. The dried *P. edule* kernels were then ground to fine particles using food processor and then dried for the second time in the oven to remove excess moisture. The oil extraction process was carried out using Soxhlet apparatus using n-hexane as a solvent, and the duration of each extraction process was set at approximately 4 h under temperature of 343 K (reflux temperature of the solvent). *P. edule* oil was obtained after separating the mixture of solvent and oil using rotary evaporator. The resultant *P. edule* oil was decanted mechanically to remove impurities and other components (glycosides) that may be present in the oil.

2.3 Apparatus for Biodiesel Production

In this study, a small-scale (1L) Jacketed glass batch reactor (Brand: Favorit) consisting of reflux condenser to recover methanol, overhead mechanical stirrer (IKA EUROSTAR digital), circulating water bath, hoses, refrigerator and sampling outlet was used to produce biodiesel from crude *P. edule* oil (CPEO). Figure 2 shows the experimental set-up used to perform biodiesel production.

2.4 Determination of Physical and Chemical Properties of CPEO, PEME and PEME–Diesel Blends

The important physical and chemical properties such as viscosity, density, calorific value, cloud point, pour point and cold filter plugging point of crude *P. edule* oil (CPEO), *P. edule* methyl ester (PEME) as well as its blends with diesel are determined and presented in this study. Table 1 shows the apparatus used in this study to measure to perform this analysis beside the country of manufacture of all equipment [10,24,25].

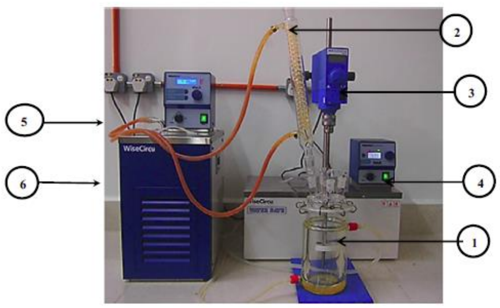

Fig. 2 Experimental set-up used to perform biodiesel production. (*1*) 1L Jacketed glass batch reactor (Brand: Favorit); (*2*) reflux condenser; (*3*) overhead mechanical stirrer (IKA EUROSTAR digital); (*4*) circulating water bath; (*5*) hoses; (*6*) Refrigerator

2.5 Determination of Saponification Number, Iodine Value, and Cetane Number of (PEME)

The cetane number (CN), iodine value (IV) and saponification number (SN) of PEME were determined empirically using the following equations [26–28]:

$$SN = SUM\left(\frac{560 \times A_i}{MW_i}\right) \quad (1)$$

$$IV = SUM\left(\frac{254 \times D \times A_i}{MW_i}\right) \quad (2)$$

$$CN = \left(46.3 + \left(\frac{5458}{SN}\right) - (0.225 \times IV)\right) \quad (3)$$

where A_i is the percentage of each component, D is the number of double bond, and MW_i is the molecular mass of each component.

2.6 Biodiesel Production Method from Crude *Pangium edule* Oil (CPEO)

The high acid value of crude *P. edule* oil (CPEO) (19.62 mg KOH/g oil) prevents the use of *alkaline-catalysed process*. Thus, a two-step process (acid–base catalyst) was used to reduce the high acid value of *P. edule* oil in the first stage and then to methyl ester in the second stage. Figure 3 shows the adopted methodology to produce biodiesel from CPEO.

Table 1 Summary of the apparatus used to measure the properties [10,24,25]

No.	Property	Equipment	Manufacturer	Test method
1	Kinematic viscosity	SVM 3000 Stabinger Viscometer	(Anton Paar, UK)	ASTM D445
2	Density	SVM 3000	(Anton Paar, UK)	ASTM D1298
3	Oxidation stability	873 Rancimat	(Metrohm, Switzerland)	EN ISO 14112
4	Flash point	Fully automatic Pensky-martens flash point -NPM 440	(Norma lab, France)	ASTM D93
5	Cloud and pour point	Fully automated cloud and pour point tester-NTE 450	(Norma lab, France)	ASTM D2500, ASTM D97
6	Cold filter plugging point	Fully automated cold filter plugging point tester-NTL 450	(Norma lab, France)	ASTM D 6371
7	Caloric value	C2000 basic calorimeter	(IKA, UK)	ASTM D240
8	Viscosity index	SVM 3000	(Anton Paar, UK)	N/A
9	Refractive index	RM 40 Refractometer	(Mettler Toledo, Switzerland)	N/A
10	Transmission	Spekol 1500	(Analytical Jena, Germany)	N/A
11	Absorbance	Spekol 1500	(Analytical Jena, Germany)	N/A

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