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Physio-chemical assessment of beauty leaf (*Calophyllum inophyllum*) as second-generation biodiesel feedstock

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ABSTRACT

Recently, second-generation (non-vegetable oil) feedstocks for biodiesel production are receiving significant attention due to the cost and social effects connected with utilising food products for the production of energy products. The Beauty leaf tree (*Calophyllum inophyllum*) is a potential source of non-edible oil for producing second-generation biodiesel because of its suitability for production in an extensive variety of atmospheric condition, easy cultivation, high fruit production rate, and the high oil content in the seed. In this study, oil was extracted from Beauty leaf tree seeds through three different oil extraction methods. The important physical and chemical properties of these extracted Beauty leaf oils were experimentally analysed and compared with other commercially available vegetable oils. Biodiesel was produced using a two-stage esterification process combining of an acid catalysed pre-esterification process and an alkali catalysed transesterification process. Fatty acid methyl ester (FAME) profiles and important physicochemical properties were experimentally measured and estimated using equations based on the FAME analysis. The quality of Beauty leaf biodiesels was assessed and compared with commercially available biodiesels through multivariate data analysis using PROMETHEE-GAIA software. The results show that mechanical extraction using a screw press produces oil at a low cost, however, results in low oil yields compared with chemical oil extraction. High pressure and temperature in the extraction process increase oil extraction performance. On the contrary, this process increases the free fatty acid content in the oil. A clear difference was found in the physical properties of Beauty leaf oils, which eventually affected the oil to biodiesel conversion process.

However, Beauty leaf oils methyl esters (biodiesel) were very consistent physicochemical properties and able to meet almost all indicators of biodiesel standards. Overall this study found that Beauty leaf is a suitable feedstock for producing second-generation biodiesel in commercial scale.

Therefore, the findings of this study are expected to serve as the basis for further development of Beauty leaf as a feedstock for industrial scale second-generation biodiesel production.

1. Introduction

Rapid growth in population, urbanisation and energy demand, together with the reduction of conventional petroleum-based oil reserves and degradation in air quality are continuously motivating researchers to find more sustainable and cleaner energy sources.

Abbreviations: FAME, Fatty Acid Methyl Ester; ASTM, American Society for Testing and Materials; FFA, Free Fatty Acid; BLOME, Beauty Leaf Oil Methyl Ester; COME, Canola Oil Methyl Ester; POME, Palm Oil Methyl Ester; ROME, Rapeseed Oil Methyl Ester; SOME, Sunflower Oil Methyl Ester; GC-FID, Gas Chromatography and Flame Ionisation Detection; ACL, Average Chain Length; ANDB, Average Number of Double Bond; KV, Kinematic viscosity; HHV, Higher Heating Value; AN, Acid Number; OS, Oxidation Stability; IV, Iodine Value; CN, Cetane Number; FP, Flash Point; CFPP, *Cold Filter Plug Point*; CPWS, Plant and Water Sciences; BERF, Biofuel Engine Research Facility; CTCB, Centre for Tropical Crops Biocommodities; QUT, Queensland University of Technology; CQU, Central Queensland University.

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As a consequence, biodiesels produced from vegetable oil feedstocks are receiving significant attention as an option to fossil-based diesel. The first recorded production of biodiesel occurred in 1937 via transesterification and using palm oil as feedstock. Biodiesel research continued from this time, but its potential was not fully realised until the 1970s energy crisis when interest in alternative fuels was renewed (Jayed et al., 2009). Since this time, a multitude of feedstocks for biodiesel has been assessed for industrial scale production. In general, biofuels offers numerous profits over fossil-based fuels including ability to produce from regionally available biomass sources, lower greenhouse gas emissions, enhanced biodegradability, and enhanced sustainability characteristics (Reijnders, 2006; Ellabban et al., 2014). Biodiesel typically contains 10%–45% of O_2 by weight while fossil-based diesel has virtually do not contain any O_2. This higher O_2 content in biodiesel helps for better and complete combustion compared with petroleum diesel. Moreover, biodiesels typically contain less sulphur and nitrogen that improves air quality from fuel combustion (Hoekman et al., 2012). At the same time, the rise in production and consumption of biodiesels has focused attention on biodiesel quality standards (Behçet, 2011).

A large number of potential biodiesel feedstocks have been examined in last few decades (Goodrum and Geller, 2005; Holser and Harry-O'Kuru, 2006; Rahman et al., 2014; Raadnui and Meenak, 2003; Lin and Li, 2009; Marchetti et al., 2008; Leung and Guo, 2006). However, only a few feedstocks including rapeseed, soybean, sunflower, tallow, waste cooking oil, etc. are being utilised for the commercial produced of biodiesel at industrial scale (Jahirul et al., 2013). These commercial biodiesels are made using edible oil feedstocks and are typically referred to as first-generation biodiesels (Rashid and Anwar, 2008). The prime criticism of first-generation biodiesels is that it is using edible oil and high-quality agricultural land for biodiesel production. Farmers have the option to sell the vegetable oil to the food market or the biodiesel production market. If the biodiesel production market is offering a higher price, farmers will choose this option more often than not to make a living. This is of specific concern in poorer nations where yields utilised for biodiesel generation dislodge the creation of nourishment harvests, hence bringing about a lack. Supply and interest direct that a deficiency will result in a value climb, which nations, for example, Malaysia are as of now encountering. This issue brought on worldwide open deliberation because of the 2007–2008 world nourishment value emergencies. Distinctive contentions exist in regards to the reason for this emergency. However, there has been the hypothesis that the expanded utilisation of biodiesel brought about a nourishment deficiency and resulting cost increment (Kingsbury, 2007). Thus, an option must be considered which wipes out the hindrances of conventional first-generation biodiesels that do not compete with food production.

In a recent study (Ashwath, 2010), a substantial number of non-eatable oil seed plants were been identified which have the potential to be used as biodiesel feedstocks. Those feedstocks are commonly referred as second-generation biodiesel that have the ability to grow on previously cleared or degraded land. Among those, *Beauty leaf* was recognised as one of the most potential feedstock biodiesel production as a result of the high oil productivity of the seeds. *Beauty leaf* is a moderately sized (8–20 m high) plant, grows in mixed cultures with minimal cultivation (Mohibbe Azam et al., 2005). The tree naturally grows in the sub-tropical and tropical atmosphere (with in the temperature between 18 and 33 °C) and free draining soils close to shorelines. It is frequently found in clay soils within Australia, India, Sri Lanka and throughout central and southern Asia including Indonesia (Jahirul et al., 0000). Moreover, the *Beauty leaf* tree has the potential for the production of 16,000 kg of dry oil bearing seeds in a year utilising one hector of the land area (Mohibbe Azam et al., 2005; Okano, 2006). However, the potential of *Beauty leaf* oil as a source of second-generation biodiesel is yet to be utilised commercially because of the absence of knowledge on the production process and biodiesel quality. Therefore, this study aims to access different oil extraction methods for *Beauty leaf* oil seed and to evaluate the quality of the oil and biodiesel produced.

2. Methods

2.1. Beauty leaf oil seed preparation

Seed preparation is critical in optimising the oil extraction process from plant to oil seed. This is because the physical conditions such as size, hardness and dryness of seeds and kernels varies significantly from one species to another. Several steps are involved including seed collection, kernel extraction and drying. Fig. 1 shows *Beauty leaf* seed preparation steps and brief descriptions of these steps are given in following sections.

Dry *Beauty leaf* seeds were mostly collected from the coastal locations of northern Queensland, Australia though local seed supplier. The seeds were than cracked open manually to expose and obtain the oil bearing kernels. To reduce kernel damage and oil loss, seed-cracking was done with care using two tools that are stompers and mallets. About 51 kg of useable wet kernels was produced from cracking of 140 kg of *Beauty leaf* seeds resulting in a kernel yield of 36%. Assuming a seed productivity of 16,000 kg of dry seeds per year per hectare, it is likely that the *Beauty leaf* plant can produce ∼5800 kg of wet kernel per year in a hectare of land area.

The kernels of *Beauty leaf* seeds naturally contain high moisture that needs to be removed for effective oil extraction. Drying was conducted using Kernels were put in the foil trays; by 2 kg per tray to guarantee the kernels was spread enough for uniform drying. A Clayson Electric oven with temperature controller was used for this purpose. The trays were weighed before placed in the drying oven for three days at 40 °C. After that the temperature of the oven was increased to 70 °C and the drying progress was monitored by measuring the weight of a few times in a day. Because a fan-forced oven was used, the tray positions in the oven seemed to impact on its drying, especially those trays nearest to the oven walls. To reduce this effect, the trays were rotated in the oven to ensure uniform drying rates. The seed was dried until it was observed that the weight was remaining constant for one day. The moisture content of the kernels was approximately 32%. Therefore, it is expected that about 3960 kg of the dry kernel can be produced from *Beauty leaf* plant per hectare per year.

2.2. Oil extraction

Oil was extracted from the kernel by three different methods that are: mechanical oil extraction, chemical oil extraction at the atmospheric condition and accelerated solvent extraction under high pressure and temperature condition. Each of the extraction methods has its advantages and limitations. A brief description of the oil extraction methods conducted in this study is given in the following sections.

2.3. Mechanical oil extraction using oil press (OP)

A Mini 40 electric motor powered screw press shown in Fig. 2 was used for the mechanical oil extraction. Beauty leaf kernel was found to be very hard to process utilising the screw press due its physical properties, and several cycles were required to extract the oil. It was also difficult to control the soft kernel paste after one pass and to keep the process clean. Two operators were obliged to go continually to the screw press, and the rate of oil generation