

PONGAMIA SEED: A POSSIBLE SOURCE OF GREEN ENERGY FOR POWER GENERATION

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Pongamia (*Pongamia pinnata*) is a prospective biofuel plant with 35 to 45% seed oil. The physical and chemical characteristics of pongamia oil are quite comparable to those of diesel. Pongamia seed oil has been considered as a possible biodiesel source for the past 10 years. The high viscosity and Conradson carbon residue of pongamia oil, however, preclude its usage in this capacity. Thus, methyl ester was produced from pongamia oil by optimising the different parameters of transesterification reaction viz., reaction time (90 minutes), amount of catalyst (1.5 wt. %), amount of methanol (210 ml per liter of oil) and optimum temperature (50 °C) needed to complete the conversion of oil into methyl ester. The produced methyl ester was employed as fuel instead of diesel in the engine test using a single-cylinder, naturally aspirated, direct injection diesel engine. Parameters such as engine speed, electrical efficiency, lower and higher heating values, and fuel consumption were investigated. Speed regulation and voltage regulation in the engine experiment provided clear evidence that the biodiesel from pongamia oil could be used in an existing diesel engine without any engine modifications. The physical and chemical properties of the methyl ester were also estimated. The biodiesel produced from quality pongamia seed meets the cetane number (52.90) and iodine value (99) as per the biodiesel quality specifications and can be used in varied climatic conditions.

Keywords: *Pongamia pinnata*, pongamia seed, seed viability, biodiesel, electrical efficiency, engine study

INTRODUCTION

Pongamia (*Pongamia pinnata* L.), family (Leguminosae), subfamily (Papilionoideae), is a medium-sized tree with a trunk diameter of more than 50 cm is also known as Karanj or pungan (Sangwan et al. 2010, Venkatesh et al. 2003). *Pongamia* grows naturally along sea shores and river banks throughout tropical Asia, including the Seychelles Islands, South East Asia, Australia and India (Arote & Yeole 2010). In India, fresh pongamia seed will be available every year from April to June.

The increasing use of diesel fuel has depleted fossil fuel carbon reserves. This sparked immediate efforts to search for alternative fuels to complement or substitute fossil fuels. Plant biomass and animal fat have been the subject of research in recent years for fuel production (Bass 2009, Martini & Shell 1998, Mohiddin 2021). It is well established that high-viscosity fuels from vegetable oil and animal fats trigger serious issues on engine efficiency and

operation of a combustion-ignition engine (Yahya & Marley 2000, Goering et al. 1987). Chemically converting vegetable oils and animal fats into their corresponding esters was one of the methods that had been widely studied to reduce the viscosity in the presence of catalysts (National Biodiesel Board 2021) by the trans-esterification process (Ayoub et al. 2021). Furthermore, increased use of hydrocarbon-based fuels result in a significant amount of emissions causing pollution. In 2018, the CO₂ emission from transport sector was around 1870 million metric tonnes and at 28% of the total greenhouse gas emission (EPA 2021). The majority of biodiesel studies indicated that it increased nitrogen oxide emissions while decreasing carbon dioxide, total particulate matter and carbon monoxide emissions (Lin et al. 2011, Singh et al. 2020). On the other hand, biodiesel does not contain sulphur which makes catalytic converter technology more effective at decreasing

nitrogen oxide emissions. The US Environmental Protection Agency and the Food and Drug Administration have recognised biodiesel as a renewable alternative fuel or supplemental fuel (Lin et al. 2006).

The constant increases in the cost of imported oil have affected the local economies of many nations throughout the world, including India and many other developing nations. Many have turned to alternative fuels such as biofuels for their daily use. Due to the fact that most nations restrict the use of edible oil for the production of biofuel, non-edible oil is currently recommended as a remedy for the aforementioned problem. Non-edible oil seeds, such as those from *Jatropha curcus*, *Pongamia pinnata*, *Madhuca longifolia*, *Calophyllum inophyllum* and *Simarouba glauca*, among others, have been identified to be the main source for the production of biofuels. Among that, pongam seeds had highest oil content of more than 40% and more number of trees are grown in India both in the forest and inland area under the urban area project greening project (Bobad & Khyade 2012).

This experiment served as a comparative study of pongamia oil-based methyl ester as a diesel fuel substitute based on the arguments presented above. The main aim was to investigate biofuel’s engine efficiency and power generation capacity, as well as the physical and chemical characterisation of the methyl esters obtained from pongamia seed (Figure 1).

MATERIALS AND METHODS

Experimental material

Physiologically matured and physically pure seeds of *Pongamia pinnata* were collected from arboretum maintained at Tamil Nadu Agricultural University, Coimbatore, India. Collected seeds were dried to the moisture content of 7.3% (ISTA 1985). Dried seeds were subjected to seed physiological quality assessment.

Physiological quality analysis of pongam seeds

Collected pongam seeds were tested for physiological quality parameters such as seed germination and vigour as per the protocol recommended by ISTA (1985). Antioxidant enzymes activities of pongam seeds were assessed by following the methodologies below:

Catalase (CAT)

The catalase activity of the pongamia seed lot used in this experiment was assessed based on Luck (1974). Seeds were preconditioned before tested for catalase activity. One gram of seeds was pulverised in a pestle and mortar with 20 ml of 0.067 M phosphate buffer, which was prepared by dissolving 3.522 g of KH_2PO_4 and

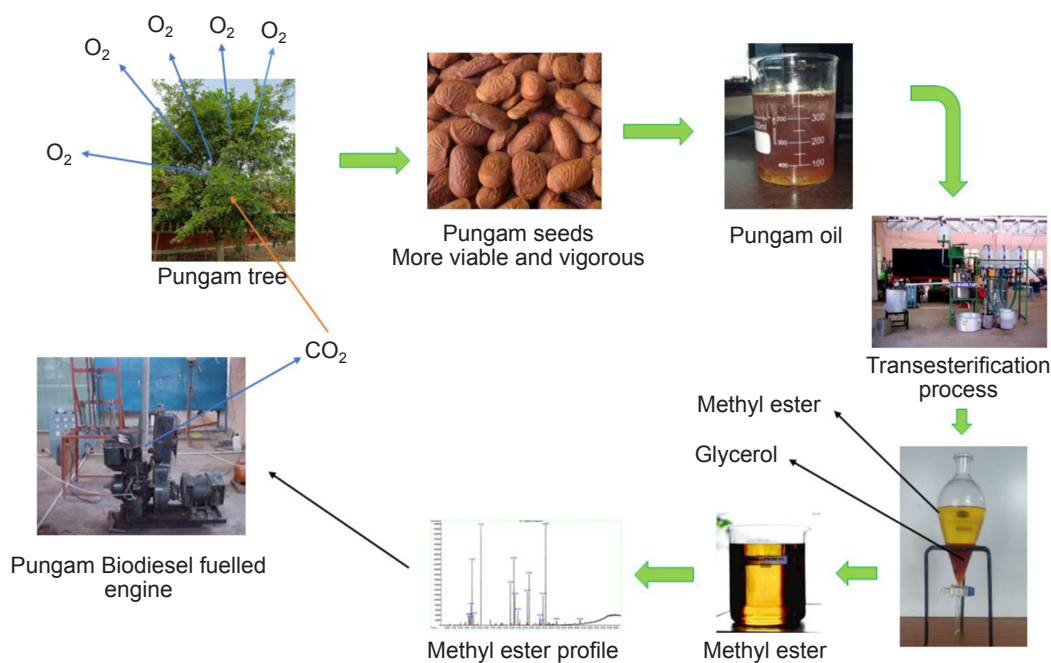


Figure 1 Process flow of methyl ester production from *Pongamia pinnata* seed

7.268 g of $\text{Na}_2\text{HPO}_4 \cdot 2\text{H}_2\text{O}$ in distilled water. The volume was then increased to one litre (the assay buffer was diluted ten times), heated to 40 °C, and centrifuged at 15000 rpm for five minutes. The enzyme assay was conducted using the supernatants. Three ml of H_2O_2 phosphate buffer, 0.16 ml of H_2O_2 (10% w/v) diluted to 100 ml with freshly made phosphate buffer, and 0.02 ml of sample were added to an experimental cuvette and thoroughly stirred with a glass rod. In the UV spectrophotometer, the time (t) necessary for a reduction in absorbance was observed at 240 nm. The catalase activity was measured in units/g of tissue and expressed as follows.

$$\text{Catalase activity (units/g)} = \frac{17 \times 10 \times 20 \times 1000}{\Delta t \times X \times Y}$$

where Δt = time required to decrease the absorbance, X = volume of enzyme extract and Y = volume of buffer solution.

Superoxide dismutase

The superoxide dismutase activity of pungam seeds was analysed based on Beauchamp and Fridovich (1971). One gram of pungam seed was pulverised in a prechilled pestle and mortar with 10 ml of ice-cold, 50 mM potassium phosphate buffer at pH 7.8. The preparation was centrifuged in a refrigerated centrifuge at 10,000 rpm for 10 min at 4 °C. The source of the enzymes was the supernatant. 50 mM potassium phosphate buffer, pH 7.8, 13 mM methionine, 2 mM riboflavin, 0.1 mM EDTA, 75 mM NBT and 50 μl of enzyme extract were mixed in duplicates to create a 3 mL reaction cocktail. An equal amount of distilled water was added to make up the volume. In order to calibrate the spectrophotometer, a blank was created without enzyme and NBT. As a reference control, another control was used which included NBT with no enzyme. For 15 minutes, the entire preparation was exposed to a 400W lamp. The absorbance was measured at 560 nm, immediately after exposure. The activity was expressed in units of enzyme activity per mg of protein.

Superoxide dismutase activity (units/mg)

$$= \frac{\text{Test OD} - \text{Control OD}}{\text{Test OD}} \times 100$$

Glutathione content (GSH)

Glutathione content was calculated using a modified method and Ellman's reagent (Ellman 1959). A volume of 0.5 ml of pungam seeds sample was pulverised with 5 ml TCA 50%. Test tube was filled with 0.02 ml DTNB reagent, 0.2 ml TCA, 0.2 ml distilled water, and 0.8 ml Tris base buffer. The absorbance was measured at 412 nm.

Dehydrogenase activity

After preconditioning, 25 pongamia seeds were soaked in water for 6 hours in four replicates to remove the seed coat. The seeds were incubated for 4 hours in a 0.2% tetrazolium chloride solution in complete darkness. The seeds were carefully rinsed with distilled water following incubation, and their surfaces were dried with blotting papers. The tetrazolium chloride solution was then decanted. The stained seeds were soaked in 5 ml of methyl cellosolve (2 methoxy ethanol) to elute the formazon. The optical density was then measured at 470 nm using a UV-VIS spectrophotometer, and the dehydrogenase activity was represented as an OD value (Kittock & Law 1968).

Oil extraction

Cleaned and dried pungam seeds were subjected to oil extraction by cold pressing process (Suresh et al. 2019). Extracted oil was subjected to methyl ester production by following the methodology given below:

Fatty acid methyl ester production

Pongamia pinnata oil was filtered via cloth primarily to eliminate impurities. Filtered oil was added to a reactor which consists of a condenser, thermometer and stirrer. In order to remove the water contamination contained in the oil, the raw oil was heated to near boiling temperature while stirring. Subsequently, the oil was allowed to cool at ambient temperature. Only treated oil was used to produce methyl ester and glycerol. The treated oil was once again heated to the necessary temperature while being stirred. In order to start the reaction, a predetermined quantity of newly prepared sodium hydroxide-methanol solution was added to the oils. The process of heating

and stirring was continued until the glycerol and methyl ester were separated from the oil. The reaction byproducts were allowed to settle overnight. Two separate liquid phases were generated during the settling process. Glycerol phase was at the bottom and crude ester phase was at the top (Eevera et al. 2009). In order to dispose the extra alkali in the finished product, crude methyl ester was separated and washed with water. The excess methanol and water in the ester phase were then evaporated at room temperature. The weight of the ester was recorded as product yield. The different steps of the reaction were carried out. The best value for each process parameter was established while keeping the constant values of the other parameters. Each time an ideal value was determined, the next parameter was optimised using obtained value.

Chemical characterization of methyl ester derived from pongam seeds

Purified pongamia oil derived methyl ester was analysed for its physical and chemical properties. Chemical properties like acid value (AV) (Cox & Pearson 1962), free fatty acid (Cox & Pearson 1962), saponification value (SV) (Horwitz et al. 1975), peroxide value (Cox & Pearson 1962) and iodine value (IV) (Horwitz et al. 1975) of methyl ester derived from pongamia oil were estimated based on the AOCS Protocols (AOCS 1998). Cd 18–90, Ca 5a-40, Cd 3–25, Cd 8–53, and Cd 1–25, respectively, cetane number (CN) and higher heating value (HHV) were calculated from the following equation by using estimated SV and IV values (Krisnangkura 1986).

$$\text{CN} = 46.3 + 5458/\text{SV} - 0.225 \times \text{IV} \quad (1)$$

$$\text{HHV} = 49.43 - [0.041(\text{SV}) + 0.015(\text{IV})] \quad (2)$$

Gas chromatography was used to examine the profile of the fatty acid methyl ester produced from pongamia oil using an HP-88 (60m × 0.25mm, 0.20um) column. Hydrogen (40 ml/min) and zero air (250 ml/min) were used as the carrier gases for the analysis. The initial column temperature was set at 40 °C for around 2.0 minutes, and the ramping temperature was set at 55 °C per minute until the column temperature reach 170 °C, and then 10 °C until the final column temperature reached 215 °C.

The carrier gas flow rate was set at 1.0 mL min⁻¹. In this experiment, a flame ionisation detection and 10 µL of the produced material were used for quantitative analysis (Christiaan et al. 2019).

Calorific value

Calorific values were determined in an electrically monitored bomb calorimeter. The tests conformed by ASTM Standard No. D 2015 (ASTM 1984).

Physical property of fatty acid methyl ester produced from pongamia seed

The physical properties of fatty acid methyl ester produced from the pongamia seed was measured as per the standard test procedure. The kinematic viscosity (×10⁻⁶ Ns m⁻²) was determined by Ostwald de-wale model. Specific gravity was measured by Specific gravity Bottle method, moisture content (wt.%) and refractive index was estimated under laboratory conditions (Demirbas 1998, Hodl 1994).

Engine test

All test runs were conducted using a single-stroke, naturally air-cooled, direct-injection diesel engine, model IS4722, with the following specifications: single phase, 5 kVA, 220 V, 22 A, and 1500 RPM.

The engine was initially run with diesel under various load situations in order to establish the baseline data. Thereafter, fatty acid methyl ester made from pongamia oil underwent a similar test run under various load circumstances. A 15-min start-up period preceded each test run in order to achieve steady state conditions and reduce any fuel leftovers. Data on fuel consumption at various load circumstances, voltage regulation at zero to full load (V_o), and speed regulation at zero to full load (N_o) conditions were gathered from the various test runs with the purpose to calculate voltage and speed regulation using the formula below:

$$\begin{aligned} &\text{Voltage regulation (\%)} \\ &= (V_o - V) / V \times 100 \end{aligned} \quad (3)$$

$$\begin{aligned} &\text{Speed regulation (\%)} \\ &= (N_o - N) / N \times 100 \end{aligned} \quad (4)$$

Based on the fuel consumption, Higher Heating Value, and Fuel Density values recorded from the test, a simulation was run using HOMER; a micro power optimization programme developed by the National Renewable Energy Lab in the United States to ascertain the specific fuel consumption, annual fuel consumption, and electrical efficiency of the engine based on the load pattern shown in Figure 2. HOMER simulates the operation of a system by doing energy balancing calculations for each of the 8,760 hours in a year. Each hour electric demand has been matched to the amount of energy that the system can produce during that time. In reality, the size and shape of the load profile will fluctuate every day. To make the load data realistic, the hourly and daily statistics are coupled with a noise input. As a result, the magnitude of the load profile varies sporadically from day to day while keeping its basic form due to daily noise. Thus, the hourly noise modifies the contour of the load profile without changing its amount. By merging daily and hourly noise, we may produce load data that appears realistic. For this simulation, there is a 10% hourly fluctuation and a 5% daily change in the load profile.

RESULTS AND DISCUSSIONS

Optimisation of catalyst concentration to maximise fatty acid methyl ester yield

A concentration range of 0.5 to 2.5 wt.% of sodium hydroxide was used to evaluate the impact of sodium hydroxide concentration on

the transesterification of pongamia oil (based on the weight of raw oil). The reaction temperature was set at 50 °C, the reaction time was set at 90 minutes, and the amount of methanol used for the experiment was 210 ml. These operating parameters were maintained during the whole reaction process. With varying catalyst concentrations, experimental results revealed differences in ester yield content. As the sodium hydroxide concentration increased, so did the triglyceride conversion and ester content. The decreased ester level indicated that there was not enough sodium hydroxide to complete the conversion of the triglycerides into esters. When the sodium hydroxide concentration reached 1.5 wt%, the ester content achieved its maximum value, and as catalyst concentration increased in all cases, the amount of ester produced dropped as shown in Figure 3. In previous studies when sodium hydroxide was added in excess, a large amount of soap was produced. According to Leung and Guo (2006) and Efavi et al. (2018), this is because using too much alkaline catalyst increased the input of triglycerides in the saponification reaction with sodium hydroxide. Thus, increasing the amount of soap produced and decreasing the ester yield.

Optimisation of reaction time to maximise fatty acid methyl ester yield

The experiment was run at 50 °C with the maximum possible mixing temperature, excess amount of alcohol (220 ml per litre of oil), and the ideal sodium hydroxide concentration of 1.5 wt% to optimize the transesterification

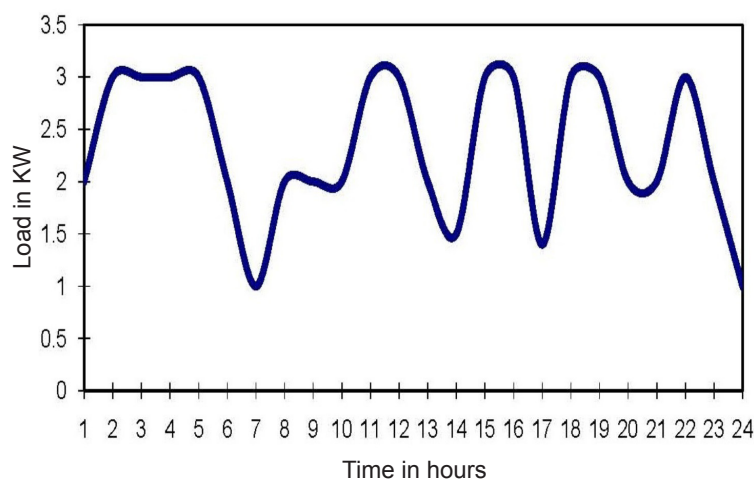


Figure 2 Load profile

reaction time. During the transesterification of the oils, the distribution of different components in the reaction system and changes in product composition with reaction time were recorded. No triglyceride was present in the resultant combination after the reaction time of 90 minutes, signifying full conversion. Within 15 minutes after starting the experiment, glycerol began to separate. From 15 minutes onwards, the ester content rose with reaction time and peaked at a reaction time of 90 minutes at 50 °C. Thereafter, the ester concentration remained largely constant as reaction time increased further (Figure 4). The findings showed that increasing the reaction time from 90 to 150 minutes had no discernible impact on the conversion of triglycerides but decreased the product yield. This is due to the fact that a longer reaction accelerated ester hydrolysis (a reverse reaction of transesterification), causing esters to be reduced and increased in the amount of fatty acids that turned into soap (Senthilkumar et al. 2019).

Optimisation of reaction temperature to maximise methyl ester yield

The transesterification process was conducted under the ideal conditions determined in the previous step using 210 ml of methanol and 1.5 wt.% sodium hydroxide in order to study the effect of reaction temperature on the formation of methyl esters. The studies were conducted at intervals of 5 °C between temperatures of 40 and 60 °C. Figure 4 depicts reaction time affected the results. The transesterification process could occur within the examined temperature range (Figure 5), according to experimental results, however the reaction time required to complete the test varied greatly with reaction temperature. It is clear that at 50 °C, a significant product yield was possible. The product yield started to decrease when the temperature rose above 50 °C. The reason behind the observation is higher temperature accelerates the side saponification reaction of triglycerides (Gulum & Bilgin 2018, Avil-Vazquez et al. 2020).

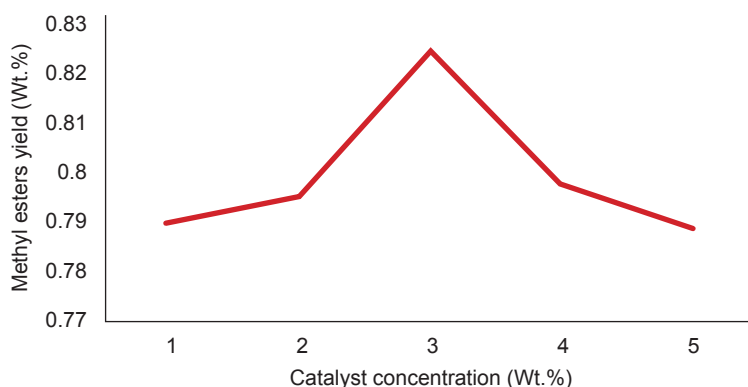


Figure 3 Effect of catalyst concentration on methyl esters yield

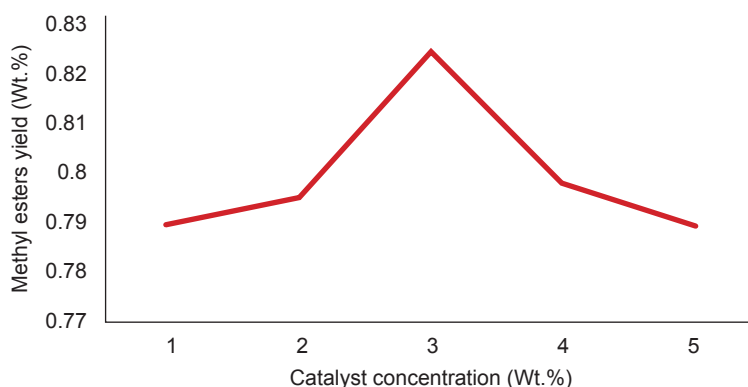


Figure 4 Effect of reaction time on methyl esters yield

Optimisation of methanol amount to maximize methyl ester yield

Different ratios of methanol to oil in the range of 120–240 ml were used to conduct the transesterification experiments to determine the impact of alcohol quantity on yield. The optimum catalyst concentration and reaction time were used, as determined in the aforementioned sections. For pongamia oils, the maximum ester content was attained at 210 ml of methanol. Very little impact on the biodiesel yield was seen as the methanol to oil ratio was increased beyond 210 ml (Figure 6).

Methyl ester chemical and physical property

Fuel properties such as specific gravity, moisture content, refractive index, acid value, free fatty acid, calorific value, iodine value (IV), saponification value (SV) and peroxide value were all estimated for the fatty acid methyl ester produced from pongamia oil. Based on the estimated SV and

IV, the cetane number (CN) and higher heating values (HHV) of Methyl Esters were determined (Table 1 and 2). The estimated SV and IV values were 189 and 99, respectively. The CN value of the pongamia methylester was 52.90 and the HHV was 40.216. In the gas chromatography analysis, totally ten major fatty acid methyl esters were detected and quantified. Among the ten, *cis*-10-pentadecenoic acid methyl ester (C15:1), γ -linolenic acid methyl ester (C18:3n6) and linolenic acid methyl ester (C18:2n6t) were found to be abundant in the detected amount (Table 3).

The rapid ignition capacity of fuel after injection is referred to as CN. A higher CN value is often correlated with better fuel ignition efficiency. This is one of the most important factors to consider when choosing methyl esters for biodiesel production. Different countries or organisations have set different minimum values based on this. Biodiesel standards of USA (ASTM D6751), Germany (DIN 51606) and European Organization (EN 14214) have set this value as

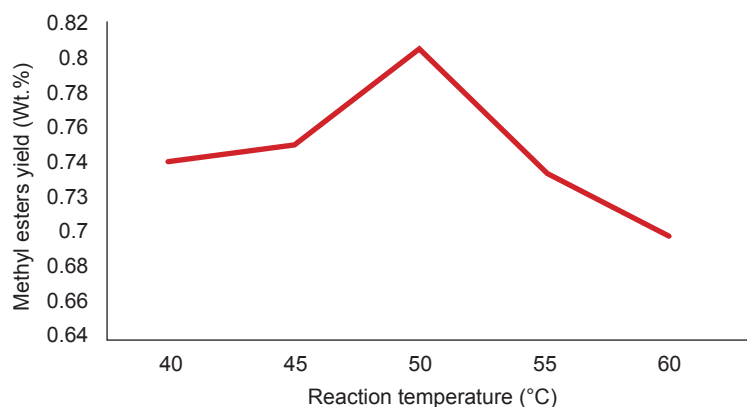


Figure 5 Effect of reaction temperature on methyl esters yield

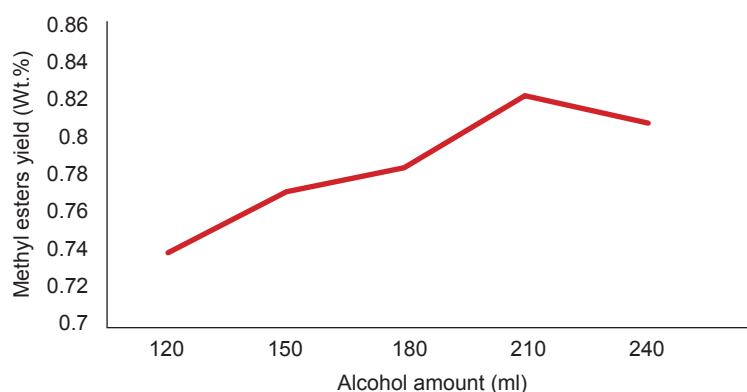


Figure 6 Effect of methanol concentration on methyl esters yield

Table 1 Physical property of fatty acid methyl esters of pongamia seed

Name of the fuel	Specific gravity	Moisture content (wt.%)	Viscosity ($\times 10^{-6}$ Ns m ⁻²)	Refractive index
Pongamia methyl ester	0.943	0.17	34.33	1.4435

Table 2 Chemical characteristics of fatty acid methyl esters derived from pongamia seed

Name of the fuel	Acid value	FFA (%)	Calorific value, (MJ kg ⁻¹)	Saponification value	Iodine value	Peroxide value	Higher heating values (KJ g ⁻¹)	Cetane number
Pongamia methyl ester	0.5	0.9	39.7	189	99	16.08	40.216	52.90

Table 3 Fatty acid methyl ester profile of pongamia seed

No	Compound name	Area (μ V.s)	Height (μ V)
1	Butyric Acid Methyl Ester (C4:0)	987.02	2217.90
2	Lauric Acid Methyl Ester (C12:0)	50520.46	7172.04
3	Myristic Acid Methyl Ester (C14:0)	252417.23	30746.86
4	cis-10-Pentadecenoic Acid Methyl Ester (C15:1)	17662357.77	913391.49
5	Palmitic Acid Methyl Ester (C16:1)	514824.48	951322.59
6	Linolenic Acid Methyl Ester (C18:2n6t)	572606.29	60798.77
7	γ -Linolenic Acid Methyl Ester (C18:3n6)	654201.46	83549.58
8	cis-11-Eicosenoic Acid Methyl Ester (C20:1n9)	158599.64	19017.78
9	Behenic Acid Methyl Ester (C22:0)	512403.98	941406.67
10	Erucic Acid Methyl Ester (C22:1n9)	16078.37	2599.04

47, 49 and 51 respectively. In our experiment, the pongamia oil derived methyl ester has a CN value of 52.90.

The degree of unsaturation expressed as IV, is another crucial factor to consider when choosing methyl ester to prevent the methyl esters from solidifying. Methyl esters with a higher level of unsaturation, however, should not be used to produce biodiesel because the unsaturated molecules will react with atmospheric oxygen to form peroxides, which cause cross-linking at the unsaturation site causing the substance to polymerize to form a body that resembles plastic. High temperatures in internal combustion engines, can speed up the process but the engine is readily clogged with polymerized methyl esters. In order to avoid this kind of circumstance, biodiesel specifications need to specify a minimum IV limit. Pongamia oil derived methyl ester with IV of 99 is less than 115, the lowest maximum limit among the three biodiesel standards set by European Organization (EN 14214).

In general, methyl esters with a higher CN content are preferred for biodiesel production. However, as CN content increases the IV value decreases. Thus, lowering the degree of unsaturation. This would cause methyl esters to solidify at higher temperatures. The upper limit of CN at 65 has been recommended in the US biodiesel norm to avoid this situation (ASTM PS 121-99). The methyl ester extracted from pongamia oil meets the CN and IV biodiesel quality specifications. As a result, biodiesel made from pongamia oil can be used in both cold and hot climates. As a contrast, Eevera et al. (2009) reported that the IV and CN value of fatty acid methyl esters derived from coconut and palm oil were not suitable for cold weather conditions.

Physiological quality of pongamia seed

The methyl ester made from pongamia oil was determined to meet the biodiesel standards set by many countries based on its physical and chemical

characteristics. The physiological quality of the seeds employed in this study had a major role in achieving the desired characteristics of the methyl ester derived from the pongamia seed. The pongamia seed lot used for oil extraction in this experiment had 91% germination and higher seed lot vigour (1974.7). Higher vigour and viability of seed protected the quality of the oil present within it by producing more amount of enzymes like SOD (1.42), catalase (2.78), glutathione reductase (0.76), and dehydrogenase (1.16) in Table 4 showing antioxidant activity. In general, seed viability and oil quality protection mechanisms are made possible by free radical and peroxide-scavenging enzymes like SOD, CAT, and GR, which support the oxide reduction cycle in the living system. The potential viability and oil quality of the pongamia seeds were directly correlated with the degree of antioxidant enzymes present in the seeds. The experimental results from the current study suggest that seed germinability is related to antioxidant defence mechanisms, which are crucial for preserving oil quality in the seed after it is harvested from the mother plant. Therefore, the physiological quality of the seed lot utilised for oil extraction in producing biodiesel is crucial to meet the biodiesel standard set by the various countries as well as for choosing the appropriate methodology for biodiesel production. The seed that was used in this experiment for biodiesel production was physiologically sound, which was reflected in the acidity value (0.5) and free fatty acid content (0.9%) in the methyl ester produced. We were able to apply the inexpensive single step alkali-

based transesterification procedure because the oil produced from the experiments had free fatty acid level of less than 1.0%. Thus, the yield of methyl ester during the transesterification process was also higher.

Engine performance and Power generation feasibility assessment

The test fuel consumption during the test run was measured and compared with diesel at various load situations in terms of litres per hour (Table 5). HOMER was used to calculate the specific fuel consumption, annual fuel consumption and electrical efficiency of the engine from a simulation based on the load pattern depicted in Figure 2 and the values were recorded for fuel consumption, Higher Heating Value, and fuel density (Figure 7, 8 and 9). Based on the simulation study, we determined the electrical efficiency, specific fuel use, and yearly fuel consumption for biofuel in contrast to diesel (Figure 10).

Figure 11 depicts the specific fuel consumption of biodiesel, revealing that biodiesel is an oxygenated fuel that can improve diesel engine combustion performance. The use of 100 percent biodiesel in the diesel engine generator resulted in incomplete combustion and slowed the release of energy from the fuel. Hence, diesel engines need to be modified in order to suit with the use of 100% biodiesel (Lin et al. 2006).

The biofuel data on speed regulation (Figure 12) and voltage regulation (Figure 13) indicated that the fuel could be used in an existing diesel

Table 4 Physiological seed quality parameters of pongamia seed used in this experiment

Parameters	Germination (%)	Vigour index	CAT activity (µM H ₂ O ₂ reduced min ⁻¹ mg of protein ⁻¹)	SOD activity enzyme (unit mg of protein ⁻¹)	GR activity (µM reduced glutathione formed min. ⁻¹ mg of protein ⁻¹)	Dehydrogenase activity (OD value)
Pungam seed	91	1974.7	2.789	1.42	0.76	1.16

Table 5 Fuel consumption (Litre/hr) at different load condition

Name of the fuel	Load kW					
	0.5	1.0	2.0	3.0	4.0	5.0
Pongamia methyl ester	0.35	0.75	1.40	1.90	2.50	3.00
Diesel	0.30	0.60	1.10	1.50	2.00	2.30

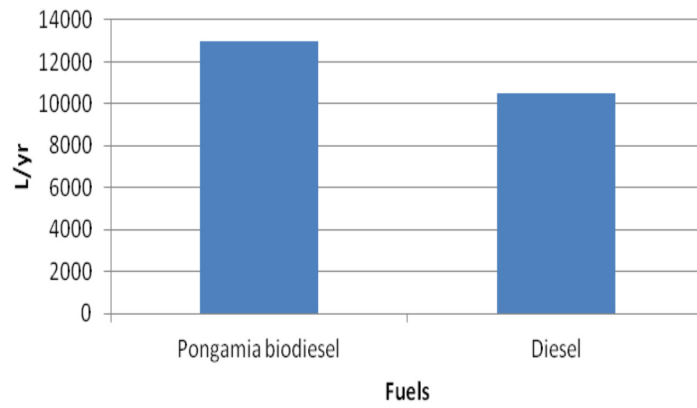


Figure 7 Fuel consumption for pongamia seed derived fatty acid methyl ester and diesel

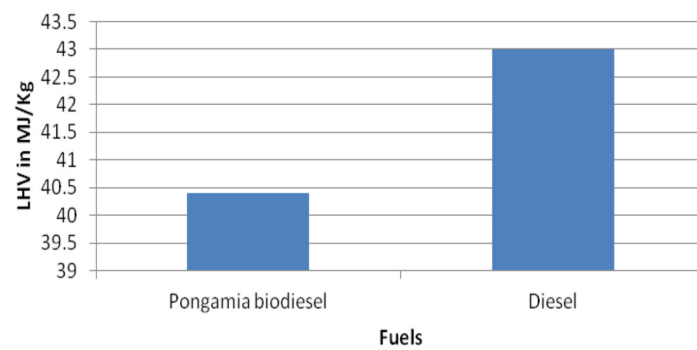


Figure 8 Lower heating values of pongamia seed derived fatty acid methyl ester and diesel

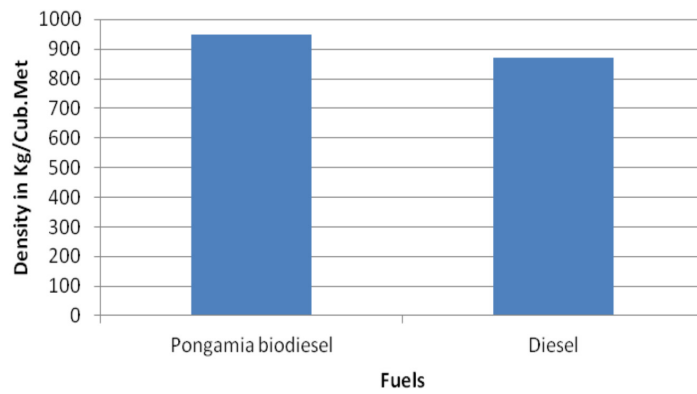


Figure 9 Density value for pongamia seed derived fatty acid methyl ester and diesel

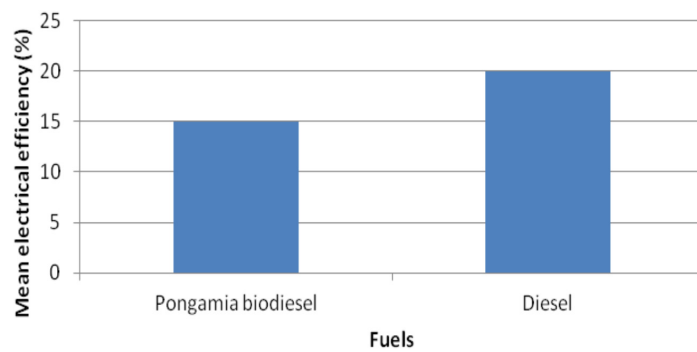


Figure 10 Mean electrical efficiency of pongamia seed derived fatty acid methyl ester and diesel

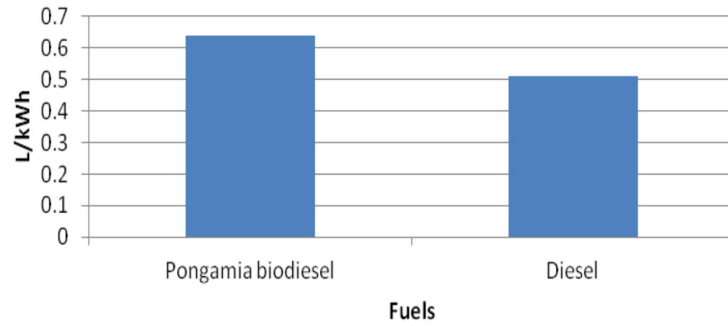


Figure 11 Specific Fuel consumption for pongamia seed derived fatty acid methyl ester and diesel

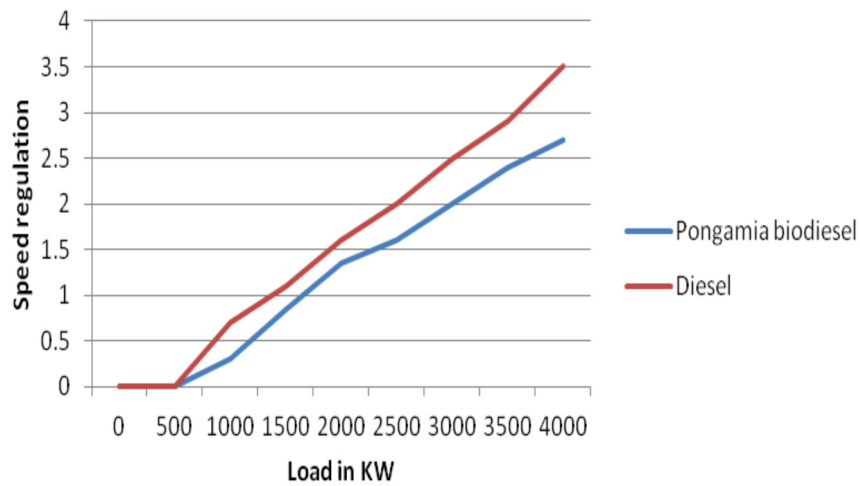


Figure 12 Speed regulation of pongamia seed derived fatty acid methyl ester and diesel

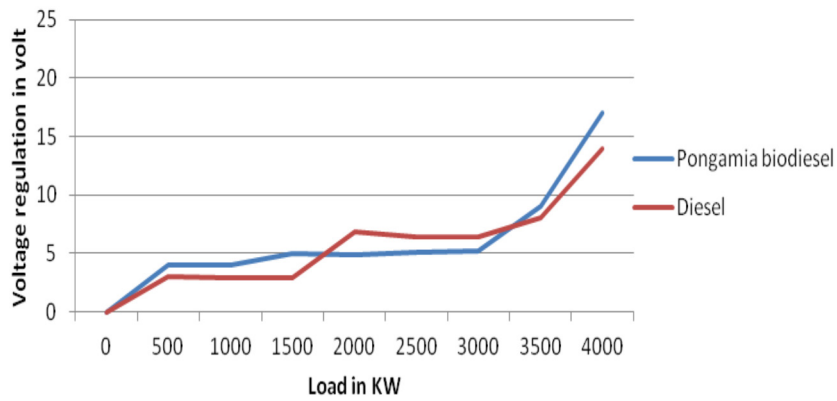


Figure 13 Voltage regulation of pongamia seed derived fatty acid methyl ester and diesel

engine. The fuel required for one year for the given load profile was also calculated through the simulation from Figure 2.

A comparison of pongamia oil-based biodiesel and diesel is shown in Figure 8. The amount of fuel required to generate 1 kWh of power is less for the oil-based methyl esters because they have a higher Lower Heating Value. Figure 10 illustrates how increased Lower Heating Value values and lower specific fuel consumption volumes improve electrical efficiency.

The use of plant oil based methyl esters is required to fill the void left by the depleting fossil fuel and the increase in crude oil prices. Unused fallow lands may be utilised and unemployed labourers problems may both be solved by the establishment and growing of non-edible oil-producing plants used for vegetable oil-based biodiesel production.

CONCLUSION

Physical and chemical property analysis of fatty acid methyl ester, and comparison with the seed vigour and viability potential of pongamia seeds indicated that seed viability was directly affected by the free fatty acid content of the pongamia oil. Whereby, the increase in the free fatty acid content of the oil resulted in decreased seed viability. Oil seeds suitability for oil extraction for biodiesel production can be assessed using their seed viability. Oilseeds with higher germination percentages are found to be appropriate for single step alkali based biodiesel production due to their low free fatty acid content. The explanation for the maintenance of superior quality oil by choosing high vigour and viability seeds was supported by the analysis of antioxidant enzymes in this experiment. Further, results from the engine test study established that fatty acid methyl ester derived from more vigorous and viable pongamia seed performs like a normal diesel fuel pertaining to engine speed and voltage modulation. Fatty acid methyl ester made from quality pongamia seed has electrical efficiency comparable to diesel. According to the international standards established by the various nations, the fatty acid methyl ester produced from pongamia seed satisfies both the CN criterion and the IV specification. In conclusion, methyl ester produced from quality pongamia seed might be a potential source of future green energy which do not require any special handling

to be used in a variety of climates like any other hydrocarbon fuel.

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