QUANTITATIVE ANALYSIS OF VARIOUS PLANT OILS USING PRIORITY ESTIMATION MODEL FOR EVALUATION OF POTENTIAL BIODIESEL FEEDSTOCK

FARHANA HAQUE NIMME

FACULTY OF SCIENCE
UNIVERSITY OF MALAYA
KUALA LUMPUR

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FARHANA HAQUE NIMME

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QUANTITATIVE ANALYSIS OF VARIOUS PLANT OILS USING PRIORITY ESTIMATION MODEL FOR EVALUATION OF POTENTIAL BIODIESEL FEEDSTOCK

ABSTRACT

Energy security, fluctuating petroleum prices, resource depletion issues and global climate change have driven countries to consider adding alternative and renewable energy options to their conventional energy share. The use of biofuel such as non-edible oils-based biodiesel is as an option over conventional diesel and could be important for the development of a sustainable and eco-friendly energy resource. The aim of the present study was to select the most feasible plant oil as biodiesel feedstock by using Analytic Hierarchy Process (AHP), one of the multi-criteria decision making methods based on priority estimation model. Among various non-edible plant oils, selection of the most feasible plant oil was evaluated based on seven criteria including seed oil yield, oil yield, free fatty acid (FFA) content, cold filter plugging point, oxidation stability, easiness to grow in marginal land, and availability in tropical areas. The obtained result from priority determination showed that, nyamplung is the most efficient source of biodiesel industry having weightage of 0.180. It is followed by kemiri sunan (2^{nd} order) having weightage of 0.164, physic nut 0.150 (3^{rd} order), indian beech 0.107(4^{th} order), indian milkweed 0.095(5^{th} order), lead 0.092 (6^{th} order), kapok 0.076 (7^{th} order), cassia 0.049 (8^{th} order), soursop 0.043 (9^{th} order) and monkey pod 0.043 (10^{th} order). This study highlights an insight into multi-criteria decision making technique to assess the feasible plant oil for biodiesel production that could aid decision-making in the industry and policy development.

Keywords: Biodiesel, biomass, feedstock, non-edible plant, Analytic Hierarchy Process (AHP)

ANALISIS KUANTITATIF PELBAGAI MINYAK TUMBUHAN MENGGUNAKAN MODEL ANGGARAN KEUTAMAAN UNTUK PENILAIAN STOK SUAPAN BIODIESEL YANG BERPOTENSI

ABSTRAK

Jaminan tenaga, kesan naik turun harga petroleum, isu penyusutan sumber dan perubahan iklim global telah mendorong negara-negara unutk menambah pilihan tenaga alternatif dan tenaga boleh baharu kepada sumber tenaga konvensional mereka. Penggunaan biobahan api seperti biodiesel dari minyak bijian yang tidak boleh dimakan ialah suatu pilihan berbanding diesel konvensional dan sangat penting untuk pembangunan kelestarian dan sumber tenaga mesra alam. Sasaran utama kajian ini ialah untuk memilih minyak tumbuhan yang paling sesuai sebagai stok suapan biodiesel dengan menggunakan *Analytic Hierarchy Process* (AHP), iaitu salah satu dari kaedah pemilihan keputusan multi-kriteria yang berasaskan model anggaran keutamaan. Di antara pelbagai minyak tumbuhan tidak boleh dimakan, pemilihan minyak tumbuhan yang paling sesuai dinilai menggunakan tujuh kriteria termasuk hasil minyak bijian, hasil minyak, kandungan asid lemak bebas, titik sumbatan tapisan sejuk, kestabilan oksidasi, kemudahan untuk ditanam di kawasan gersang serta kedapatan di kawasan tropika. Keputusan yang didapati menunjukkan, minyak nyamplung adalah paling bersesuaian dengan pemberat 0.180. Ia diikuti minyak kemiri sunan dengan pemberat 0.164, physic nut 0.150, indian beech 0.107, indian milkweed 0.095, lead 0.092, kapok 0.076, cassia 0.049, soursop 0.043 dan monkey pod 0.043. Kajian ini telah menunjukkan kebolehan penggunaan kaedah pemilihan keputusan multi-kriteria untuk membuat penilaian ke atas kesesuaian sesuatu minyak tumbuhan untuk penghasilan biodiesel dan dijangka dapat membantu proses penetapan keputusan oleh industri dan pembangunan polisi.

Kata Kunci: Biodiesel, biojisim, mentah, Tumbuhan tidak boleh dimakan, Proses Analitik Hierarki

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LIST OF SYMBOLS AND ABBREVIATIONS

%	:	Percentage
°C	:	Degrees celsius
AHP	:	Analytic Hierarchy Process
CFPP	:	Cold Filter Plugging Point
CI	:	Consistency Index
CO	:	Carbon monoxide
CO_2	:	Carbon dioxide
CR	:	Consistency Ratio
FAME	:	Fatty Acid Methyl Esters
FFA	:	Free Fatty Acid
FGD	:	Focus Group Discussion
h	:	Hour
Kg/ha	:	Kilogram per hectare
NO_2	:	Nitrogen dioxide
OPV	:	Overall Priority Vector
PM	:	Particulate Matter
RI	:	Random Index
SO_2	:	Sulfur dioxide
WCO	:	Waste Cooking Oil
wt	:	Weight

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CHAPTER 1: INTRODUCTION

1.1 General Introduction

Energy is the primary requirement of human survival and actions. The key source of energy is fossil fuels which have been used predominantly since the industrial revolution. Modern civilization has been the major cause of continuous extraction and utilization of fossil fuels (coal, natural gas and petroleum) for different kind of purposes (Rastogi *et al*., 2018). However, these sources are finite in nature and could be depleted in the near future because of its non-renewability characteristic. As fossil fuels are carbon-based energy, it is the reason of various environmental problems because of the emission of greenhouse gases (CO_2, NO_2, SO_2, CO) upon combustion (Rastogi *et al*., 2018). As a result, researchers are now focusing more and more towards renewable energy sources which have the potential of resolving many environmental concerns ranging from air pollution to global warming, as well as improving the current environmental status (Anitha & Dawn, 2010).

To be an efficient alternative of fossil fuel, a substitute should not only have superior environmental benefits, but it should be also economically competitive and be able to meet energy demand to make a positive impact (Ambat *et al*., 2018). Because of the fluctuating price, possible depletion of fossil fuel, harmful effects to the environment, transportation biofuel have gained interest as a promising alternative for diesel engines.

Biodiesel has been well received almost globally because of various factors such as renewability, eco-friendliness, non-toxicity, and biodegradability (Ambat *et al*., 2018). Based on lifecycle, biofuel reduces carbon dioxide emission (78%) compared to the conventional petroleum fuel (Carvalho *et al*., 2011). Biodiesel is the mono-alkyl esters of long chain fatty acid which is produced by transesterification or any other recommended method by using renewable lipid feedstock.

It can be found in three states namely solid, liquid, or gaseous fuels. Biodiesel can be produced from different parts of the plants such as agricultural or forestry by-products, plant residues, agricultural crops as well as municipal waste (Aburas & Demirbas, 2015).

Renewable biological sources are used to produce biodiesel including both edible and non-edible vegetable oil, waste cooking oil, fish oil, animal fats and algae (micro and macro) (Bhuiya *et al*., 2016). Manufacturing biodiesel from these sources poses various environmental benefits. One major advantage of using renewable sources is the reduced disposal problem of significant amount of used cooking oil or vegetable oil. In addition, low price of non-edible oil and used oil is considered as another benefit of using these sources for biodiesel. Moreover, used vegetable oil described as a 'renewable fuel',has less contribution in adding extra carbon dioxide to the atmosphere (Atabani *et al*., 2013).Higher biomass productivity, no need of agricultural land to produce, high viscosity, low volatility and requirement of cheap and simple nutrients are the major benefits of using microalgae (Ahmia *et al*., 2014).

Although edible vegetable oils are considered as efficient source of biodiesel, it poses various limitations such as higher viscosity, lower volatility and lower efficiency under cold conditions (Ambat *et al*., 2018). Recently, the usage of edible oils for biodiesel production has been of great concern as it competes with food materials. Besides, it is not ethical to justify the use of the edible vegetable oils for fuel purposes especially in poor countries where food is limited. Furthermore, fuels from edible oil feedstock would be expensive which turned attention to non-edible oils feedstock.

In order to overcome the aforementioned drawbacks, researchers are now focusing more on alternative sources of biodiesel such as non-edible vegetable oils. Non-edible plant oils are not suitable for human consumption as it contains toxic components

(Borugadda & Goud, 2012). Therefore, it is expected that non-edible oils would be competitive in price compared to edible vegetable oils. Some of the noteworthy advantages of using inedible vegetable oils as a diesel feedstock include higher combustion efficiency, biodegradability, renewability, liquid nature portability, ready availability, aromatic content and lower sulfur content (Demirbas *et al*., 2016).

This study will analyze various potential non-edible plants used as a biodiesel feedstock and the criteria which influence the selection of most feasible plant oil by using a multi-criteria decision making tool known as AHP (Analytic Hierarchy Process).

1.2 Research Background

Fulfillment of the oil and energy requirement depends on oil production as well as sources of oil. The energy demand is increasing day by day with an increase of the population. Biodiesel being renewable source of energy could be an efficient way of solving energy crisis.

Among different kind of biodiesel sources, it is considered that first generation biodiesel, produced primarily from food crops and mostly edible seed oil, are limited in their ability to attain targets for biodiesel production, mitigating climate change and economic growth (Shalaby, 2011). However, second generation feedstocks are more environmental friendly than first generation feedstock. Non- edible feedstocks are also competitive in quality with edible feedstock. Cultivation of non-edible crops need less farmland compared to edible crops. In addition, the by-products from the conversion process of biodiesel from non-edible feedstocks can be used in other chemical processes or in power generation. Moreover, most of the inedible oils are highly pest and disease resistant as well. Nature portability, biodegradability, easy availability, lower sulfur and aromatic content, and renewability make the second generation feedstocks more suitable for biodiesel industry (No, 2011; Ahmad *et al*., 2011).

The abovementioned concerns have increased the interest in exploring second generation biodiesel which is produced from non-edible feedstock instead of edible food crops (Shalaby, 2011).

1.3 Problem Statement

The price of biodiesel is dependent on its raw materials from which it is made of. It is estimated that, raw material cost contributes approximately 70-95% to the biodiesel cost (Ahmia *et al*., 2014; Bhuiya *et al*., 2016). For this reason, the type of raw material is crucial as it affect biodiesel commercialization.

Now-a-days, it is estimated that more than 95% of biodiesel are produced from edible oil feedstock which is the reason of a huge imbalance between human nutrition chain and fuel (Mardhiah *et al*., 2017). In developing countries where food is limited, extensive use of edible vegetable oils may be the reason of food scarcity (Balat, 2011). On the other hand, non-edible plant oils are easily available and comparatively economically feasible than edible plant oils. Non-edible oil plants can groweasily in waste lands including unfertilized and unused lands which are unsuitable for the production of food crops. Moreover, these plants can still sustain reasonably high yield without intensive care which leads to a much lower cultivation cost (Demirbas *et al*., 2016).

Biodiesel produced from non-edible vegetable oils should be explored widely which could be a potential alternative to diesel fuel to reduce food versus fuel conflict.

1.4 Research Objectives

Objectives of this study are as follows:

1. To establish the criteria influencing the selection of plant oil for biodiesel production.
2. To analyze various plants oils for biodiesel production using Analytic Hierarchy Process (AHP).
3. To suggest the most feasible plant oil for biodiesel production based on the AHP results.

1.5 Scope of Work

This study will focus on different criteria which can influence the selection of non-edible plant oil for biodiesel production. The study will also analyze various plant oils by using priority estimation model, known as AHP (Analytic Hierarchy Process) to prioritize plant oils used as biodiesel feedstock. Reducing the bias by checking consistency through AHP, the findings will be more reliable to suggest the most feasible plant oil for biodiesel production which will be helpful in decision-making in the industry and also for policy development.

1.6 Dissertation Structure

The dissertation includes five chapters namely introduction, literature review, materials and method, result and discussion and conclusion and recommendation.

The first chapter provides general introduction about the dissertation including background of the research, problem areas, aim and objectives of the study and scope of work.

The second chapter is literature review which focuses on reviewing previous study regarding biodiesel feedstocks, different generation of biodiesel, various non-edible plant oils used for biodiesel production and biodiesel standard and specification.

The third chapter provides explanation about selection method of non-edible plants, selection of criteria to evaluate non-edible plant oils as well as the procedure of selecting most feasible non edible feedstock by AHP (Analytic Hierarchy Process).

Furthermore, the fourth chapter represents all the obtained results and discussion over it.

Last but not least, the fifth chapter is the conclusion which summarizes the findings of the study and a few recommendations for future work.

CHAPTER 2: LITERATURE REVIEW

2.1 Biodiesel

Biodiesel is derived from two words namely 'Bio' which means life and diesel is named after the inventor of diesel engine 'Rudolf Diesel' (Jayed *et al*., 2011). Biodiesel is familiar as vegetable oil or animal based diesel that emit less soot, carbon IV oxide and particulate matter. Biodiesel is known as mono-alkyl esters consisting of long chain fatty acids which can be derived from animal fats or vegetable oils. The reaction process of biodiesel production can be performed with or without catalyst. It is known as alternative fuel as it causes less environmental pollution due to absence of aromatic or sulfur compounds in its composition (Atabani *et al*., 2013).

Various source of biodiesel have been found including edible vegetable oil, non-edible vegetable oil, waste cooking oil or recycled oil, animal fats and microalgae. Biodiesel is classified into three generations depending on the source of its feedstock which are namely first generation biodiesel, second generation biodiesel and third generation biodiesel (Ambat *et al*., 2018).

In general, biodiesel is characterized by following different analysis such as spectroscopic or chromatographic analysis (Ambat *et al*., 2018). The most common biodiesel production is transesterification. The other procedure includes pyrolysis, dilution, micro-emulsion etc. (Baskar & Aiswarya, 2016; Aransiola *et al*., 2014). The quality of biodiesel is determined by using different standard which varies according to the country, such as EN 14213 and 14214 in Europe, ASTM D6751 in the United States (Knothe, 2006).

2.2 Advantages and Disadvantages of Biodiesel

Biodiesel is a fuel from biological sources instead of fossil fuels (coal, natural gas). Biodiesel has become popular around the world as it is environment friendly and renewable.

One of the important output of using biodiesel is it does not pollute environment as petro-diesel does by emitting CO, SO_2, CO_2 and PM upon combustion. Since biodiesel is agriculture oriented, it is biodegradable and non-toxic. In addition, biodiesel poses high cetane number which indicates the combustion quality of fuel during compression ignition, oxygen atom in the molecule of fuel, low sulfur and volatility. The characteristic of being blended with other oil or energy sources makes biodiesel advantageous over petro-diesel. Moreover, biodiesel development could play an important role in overcoming unemployment problem in developing countries such as South-East-Asian region. It encourages agricultural sector development as well (Sakthivel *et al*., 2018; Atabani *et al*., 2012; Atabani *et al*., 2013)

However, biodiesel is not beyond limitations although it has gained much popularity among scientist in recent years. A limitation of using biodiesel is the emission of nitrogen oxides during combustion which might be the cause of forming acid rain and smog. When biodiesel is compared to petro-diesel, it has lower energy output which means more biodiesel is required than petro-diesel to produce equal amount of energy. Some other drawbacks include, low oxidative stability especially when biodiesel has polyunsaturated acid origin, less power, torque and fuel economy. Furthermore, biodiesel crop production in valuable crop land could be a cause of rise of food cost which might result food scarcity (Sakthivel *et al*., 2018; Atabani *et al*., 2012; Atabani *et al*., 2013).

2.3 Biodiesel Feedstock

A number of researches have been done all over the world regarding different kind of feedstocks used for biodiesel production. Since the biodiesel production cost is dependent on the cost of feedstock, selecting the cheapest source has been considered as the important issue for biodiesel development (Atabani *et al*., 2012). According to Silitonga *et al*. (2013), low production cost and large production scale are two important requirements to fulfill to be used as a biodiesel feedstock. Availability of feedstocks depends on geographical locations, regional climate, agricultural practices and local soil conditions of a country (Atabani *et al*., 2012; Kumar & Sharma, 2011).

Generally, biodiesel feedstocks are classified into four major groups namely: edible vegetable oil, non-edible vegetable oil, waste or recycled oil and animal fats (Demirbas, 2009; Atabani *et al*., 2012; Balat & Balat, 2010; Kumar *et al*., 2013; Azad *et al*., 2016; Kafuku & Mbarawa, 2010). Most of researchers have considered algae as a member of the group non-edible vegetable oil whereas some believe it belongs to separate group. However, it has been welcomed as emerging non-edible oil due to its high oil content and rapid biomass production (No, 2010).

While comparing various feedstocks, some parameters are considered including energy supply and balance, land availability, cultivation practices, greenhouse gas emission, soil fertility and erosion, contribution regarding biodiversity loss, transportation and storage cost, economic value of the feedstock, requirement and availability of water, and effect of feedstock on environmental quality (Balat, 2011; Ahmad *et al*., 2011; Atabani *et al*., 2012).

2.3.1 Edible Oil Sources

Edible oil sources are used for biodiesel production from the very beginning. Some of the biodiesel feedstocks which were dominating the early 1998 are rapeseed oil (RSO, 84%), sunflower oil (SNO, 13%), soybean oil (SBO, 1%), palm oil (PMO, 1%), and other oils (including *Jatropha* oil, beef tallow and recycled frying oils, 1%) (Bart *et al*., 2010). At present, edible oil is the highest contributor (more than 95%) to biodiesel production (Bhuiya *et al*., 2016). Many countries namely Germany, Malaysia and USA have established the plantation of these edible oil plants (Atabani *et al*., 2012).

However, large-scale usage of edible plant oils in biodiesel industry raises various problems such as food versus fuel dilemma, deforestation and important soil resources destruction which cause environmental problems, and conversion of valuable crop lands to energy crop (oil bearing plant) land (Balat, 2011). In last few decades, the price of vegetable oil which affects viability of biodiesel industry has also increased dramatically (Balat & Balat, 2010). Moreover, continuous usage of edible oils for biodiesel production may result a huge imbalance between demand and supply in the course of time (Atabani *et al*., 2012). For this reason, current dependency on the edible sources is considered as unworthy which stipulates the search for alternative sources (Avhad & Marchetti, 2015). To overcome above-mentioned limitations, researcher are now focusing more and more in exploiting non-edible oils as biodiesel feedstock which could be a possible solution.

2.3.2 Non-edible Oil Sources

The inedible oils are considered as the potential sources of energy supply in future. Atabani *et al*. (2012) believed that the reasons behind the attention towards non-edible sources are easy availability in many places of the world, growing capacity in marginal land which is unsuitable for edible crop plants, no competition with food, lower rate of deforestation, and much more economical than edible oil.

In nature, a large number of non-edible oil producing plants are found such as *Senna siamea* (cassia), *Albizia saman* (monkey pod), *Leucaena leucocephala* (lead), *Ceiba pentandra* (kapok), *Calotropis gigantea* (indian milkweed), *Annona muricata* (soursop), *Balanites aegyptiaca* (desert date), *Nicotiana tabacum* (tobacco seed), *Sapindus mukorossi* (soapnut), *Sapium sebiferum* Roxb. (chinese tallow), etc. (Demirbas, 2009; Atabani *et al*., 2013; Balat & Balat, 2010; No, 2011; Azad *et al*., 2016).

According to Borugadda and Goud, (2012), algae (micro and macro) are one of the best non edible oil sources of biodiesel and it could be an important solution to abate food versus fuel conflict.It is also considered economical than other sources because of its higher oil yield and photosynthetic efficiency, rapid growth compared to energy crops as well as biomass production (Sharma *et al*., 2008; Borugadda & Goud, 2012; Balat, 2011). Demirbas, (2011) mentioned that, algae yields higher oil productivity (30 times more) than other crops which are used currently for biodiesel production. Moreover it can be produced anywhere including sewage or salt water (Demirbas & Fatih, 2011; Kumar *et al*., 2013).

On the other hand, biodiesel produced from non-edible oil poses some drawbacks. One of the noteworthy limitations is the criteria increasing biodiesel production cost. These criteria include higher viscosity and carbon residue percentage, lower volatility, unsaturated hydrocarbon chains reactivity and higher amount of free fatty acid contents (FFA) (Balat, 2011; No, 2011; Demirbas, 2009; Srivastava & Verma, 2008; Leung *etal*., 2010).

2.3.3 Waste Cooking Oil (WCO)

Waste cooking oil is getting attracted by researchers as an alternative source of biodiesel because of higher price of raw and refined vegetable oils (Borugadda & Goud, 2012).

It has been observed that, considerable amount of waste lipids are producing from food processing industries including households, restaurants, fast food shops etc. A study done by Rojas-González and Girón-Gallego, (2011) showed serious environmental problems due to inappropriate disposal of the waste cooking oil into rivers and landfills. Yet, by converting waste cooking oil into fuel, it is possible to reduce environmental pollution (Phan & Phan, 2008). The fuel produced from WCO can also be used as a partial alternative to petro-diesel (Chen *et al*., 2009; Balat & Balat, 2010).

Both the physical and chemical properties of waste cooking oil got slightly altered from fresh oil due to the changes during frying. It has been noticed that, the molecular weight reduces to one-third during the conversion process namely transesterification from WCO to biodiesel. The value of viscosity, flash point and pour point also change while there is an increase in volatility (Demirbas, 2009; Balat & Balat, 2010). Thus, the usage of waste cooking oil can significantly reduce biodiesel production cost.

The usage of WCO as a biodiesel feedstock is not beyond limitation. Various impurities such as free fatty acid (FFA) content and water are found in WCO whereas FFA content leads to saponification and water is often the cause of hydrolysis (Meng *et al*., 2008; Tan *et al*., 2011).

2.3.4 Animal Fat

Fat derived from animals is the other group of feedstock for biodiesel production. Different kinds of fats are found to be used in biodiesel industry such as lard or white grease, tallow, chicken fat and yellow grease (Diaz-Felix *et al*., 2009). Animal fats are available easily in slaughter industry where these are managed well for handling procedure as well as product controlling.

The advantages of using animal fats for biodiesel production include lower free fatty acid (FFA) content and water content whereas animal fat oriented biodiesel pose renewable properties, high cetane number and non-corrosive charteristics (Balat & Balat, 2010; Gürü *et al*., 2009). On the other hand, the drawbacks of using animal fats for biodiesel includes higher pour point and viscosity, higher flash point and processing difficulties as well (Gürü *et al*., 2009).

2.4 Biodiesel Production Method

Different types of processes, methods and techniques have been oriented for biodiesel production from various feedstocks where cost efficiency is considered as a major focus in research studies. Among various methods, some are widely used for biodiesel synthesis such as transesterification, pyrolysis or thermal cracking, supercritical fluid method, dilution, micro-emulsion, catalytic distillation and reactive distillation technology (Gaurav *et al*., 2016; Baskar & Aiswarya, 2016; Aransiola *et al*., 2014). Some of the major technologies are described briefly in the following section (Figure: 2.1). Flowchart showing the conversion process of non-edible seed oil to biodiesel is presented as Figure 2.2.

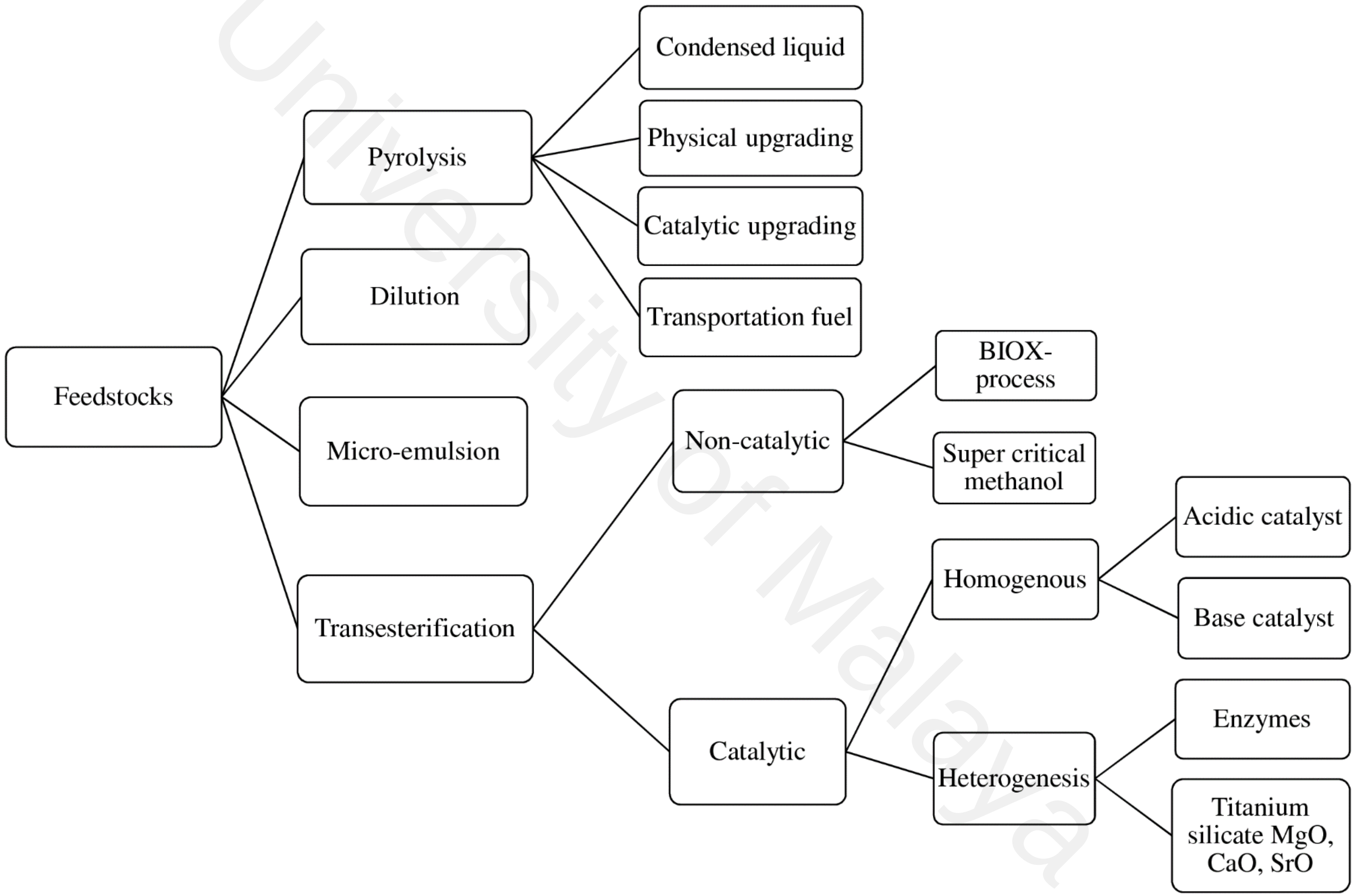


Figure 2.1: Biodiesel production methods. Image reproduced with permission from Khan *et al*., (2014).

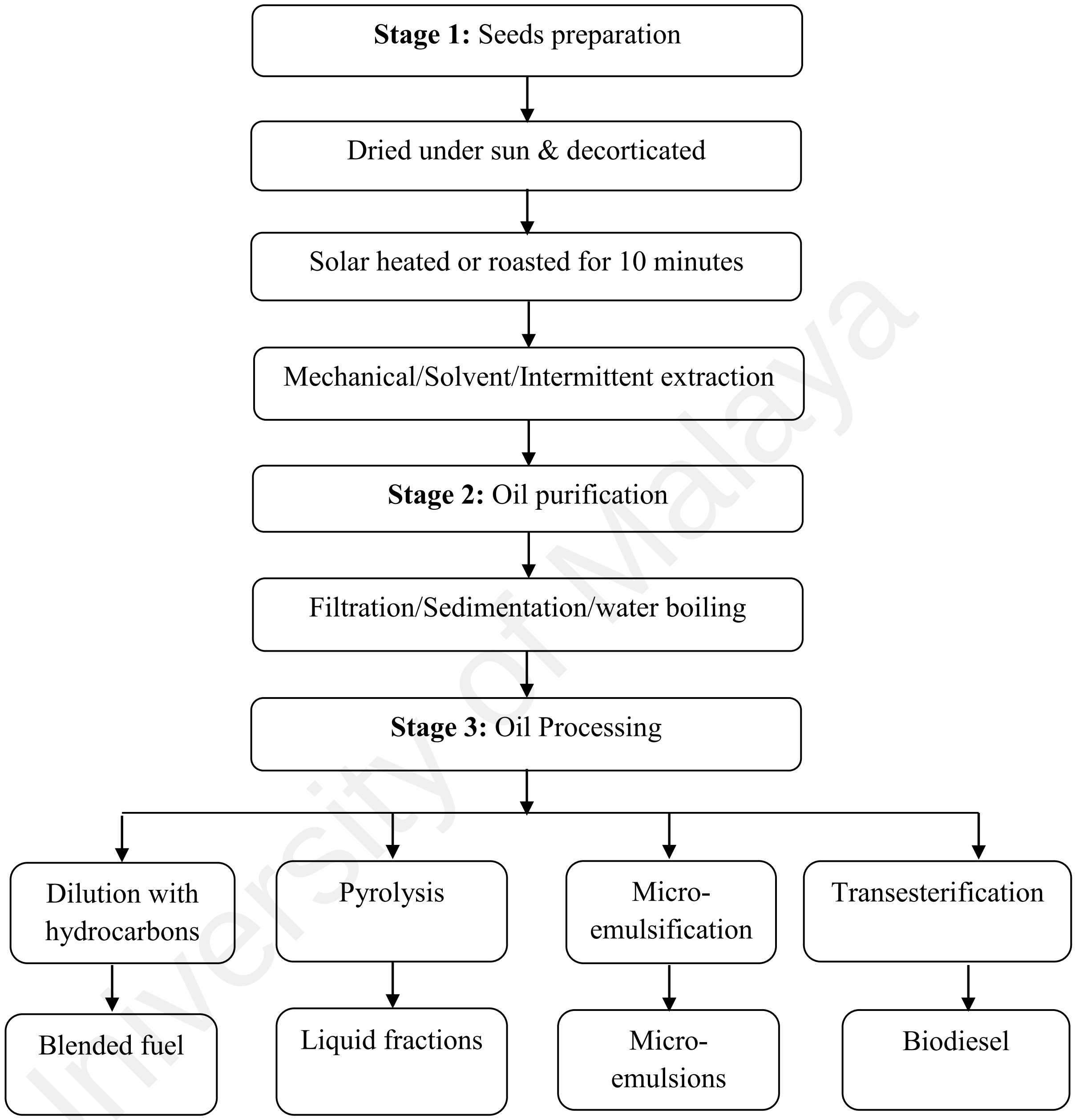


Figure 2.2: Biodiesel production procedure from non-edible plant seeds. Image reproduced with permission from Atabani *et al*., (2013).

2.4.1 Transesterification

It is considered as the most suitable method for biodiesel production. It has been applied widely in most of the biodiesel industries (Mahmudul *et al*., 2017). This process is simple and cost effective. The capacity of reducing the viscosity of oil makes it suitable for engines and equipment. Because of such reason, it has gained much popularity in biodiesel industries (Abbaszaadeh *et al*., 2012; Kout-souki *et al*., 2016). In this method, vegetable oil (triglyceride) and alcohol are converted to glycerol and methyl ester (fatty acid alkyl ester) (Koutsouki *et al*., 2016) (Figure 2.3).

$$\begin{array}{ccccccc}
CH_2\text{- }COOR_1 & & & & CH_2\text{-}OH & & R_1COOCH_3 \\
| & & & & | & & \\
CH\text{-}COOR_2 & + & 3CH_3OH & \underset{}{\overset{\text{Catalyst}}{\rightleftarrows}} & CH\text{-}OH & + & R_2COOCH_3 \\
| & & & & | & & \\
CH_2\text{-}COOR_3 & & & & CH_2\text{-}OH & & R_3COOCH_3 \\
\text{Vegetable oil} & & \text{Alcohol} & & \text{Glycerol} & & \text{Methyl ester}
\end{array}$$

Figure 2. 3: Triglycerides transesterification reaction

Transesterification process can be categorized in two ways namely catalytic and non-catalytic process (Figure 2.1). In catalytic process, a catalyst is used to increase reaction rate and the required time whereas non-catalytic process does not involve any catalyst.

2.4.2 Pyrolysis Process

The process is also known as thermal cracking in which organic materials are converted to biodiesel by applying heat. This process is conducted in the absence of oxygen and the fuel obtained from this process possess certain characteristics such as accepted amount of sulfur, less viscosity and high cetane number indicating less delay in ignition (Baskar & Aiswarya, 2016).

2.4.3 Micro-emulsion Process

Isotropic fluid is generally created from two non-miscible liquids and single or numerous amphiphiles. The micro-emulsion process involves colloidal dispersion of isotropic fluid. To get maximum viscosity, this process also includes ionic and non-ionic aqueous solution (Baskar & Aiswarya, 2016).

2.4.4 Dilution Process

This process involves the dilution of vegetable oil with traditional diesel. It was reported that, in a pre-combustion chamber engine, a mixture of vegetable oil (10%) and conventional diesel was able to maintain total power which require no change or engine tuning. Analysis was performed with the ratio of 50:50 in some other experiment (Singh & Singh, 2010).

2.4.5 Reactive Distillation

This process uses multifunctional reactor which has the ability to improve an ordinary distillation process. In a single unit, integration of the chemical reaction and thermodynamic separation are done. The end product of this technique maintains chemical equilibrium. The method is efficient for the feedstock with high free fatty acid (FFA) content (Aransiola *et al*., 2014).

2.4.6 Supercritical Fluid Method

Supercritical methanol method was invented to avoid catalyst usages and to reduce reaction time. Because of the higher miscibility of methanol and oil, this process provides faster reaction (Lee & Saka, 2010). Although, requirement of higher energy for solvent to achieve supercritical condition is considered as the drawback of the process, high speed mass and heat transfer with faster components mixing is the major advantage of using supercritical fluid method (Tan & Lee, 2011).

2.4.7 Green Reactor Technology

High quality biodiesel can be produced by using this technology. The experimental process involves both product separation and chemical reaction which act which is done in single step. During the procedure, conversion of biodiesel occurs at liquid phase while maximum methanol remains in vapor phase. The products namely biodiesel, water and glycerol can be separate easily because of their different volatility. This method is cost effective and saves significant amount of energy (Gaurav *et al*., 2016; Zhang *et al*., 2014).

2.5 Generation of Biodiesel

Biodiesel is classified into three main generations based on its source of production namely first generation, second generation and third generation biodiesel. A brief description of three generation is given in this section.

2.5.1 First Generation Biodiesel

During emergence of biodiesel, edible oils were used widely for biodiesel production. The biodiesel having the origin of food crops is considered as first generation biodiesel. The edible oil sources such as rice, corn, coconut, olive, rapeseed, mustard, wheat, soybean etc. were the first generation feedstock of biodiesel (Sakthivel *et al*., 2018).

The advantages of using edible oil sources for biodiesel production include crops availability and comparatively easy conversion process. However, using food grade plants for biodiesel production is the reason behind food versus fuel competition which leads to high food cost. High cost, restricted area of cultivation and adaptability to climatic condition also limit the usages of first generation feedstocks (Sakthivel *et al*., 2018).

2.5.2 Second Generation Biodiesel

Because of tremendous limitations of using first generation feedstock, researcher started to use various non-edible feedstocks to produce biodiesel. Biodiesel produced from non-edible feedstocks (*Calophyllum inophyllum*, *Jatropha curcas*, etc.) is termed as second generation biodiesel or advanced biodiesel (Sakthivel *et al*., 2018). It can also be produced from a variety of sources such as non-food lingo-cellulosic materials (agricultural crop residues, wood), municipal solid waste, forest harvest residues and biomass energy crops (switch grass) (Bowyer *et al*., 2018).

As second generation biodiesel emit less carbon dioxide to the environment, it is considered as a great alternative to fossil fuel than first generation biodiesel does. Since this generation biodiesel uses non-edible oil, it can be useful in eradicating food imbalance, reducing biodiesel production cost and land requirement. On the contrary, the production of second generation biodiesel is not up to commercial demand yet. Commercialization of second generation biodiesel has taken decade because of its technical challenges and complex thermo-chemical or biochemical processing. Now, second generation biodiesel is emerging as an efficient alternative diesel fuel.

Considering economic viability in a productive way and wide availability, researchers are now focusing more on novel feedstocks to overcome socio-economic problems associated with second generation biodiesel (Sakthivel *et al*., 2018).

2.5.3 Third Generation Biodiesel

Biodiesel produced from sources like microalgae, fish oil, animal fats as well as waste cooking oil is familiar as third generation biodiesel (Verma *et al*., 2016). These viable sources could be used to overcome difficulties faced by other two generations of biodiesel such as availability, economic feasibility, food versus fuel competition and adaptability to climatic conditions (Sakthivel *et al*., 2018)

The ability to survive in harsh condition makes microalgae an efficient source of biodiesel. The other advantages of microalgae are high lipid content which may vary up to 70-90% of its dry weight depending on species, high productivity and growth rate, less disturbance to food chain, lower agricultural land requirement and reduced greenhouse gas emission. Though microalgae possess lots of advantages, it has some limitations such as sunlight requirement, difficulties in oil extraction, challenges associated with commercialization and need of large capital investment (Sakthivel *et al*., 2018).

Besides microalgae, waste cooking oil proved itself as a cost effective and very heterogeneous feedstock of biodiesel as it reduces sewage treatment burden and water contamination. The animal fats obtained from beef, poultry, goat and pork, are emerging sources of biodiesel. These sources are cheap and stable compared to other feedstocks and preferred to use for raw oil production (Sakthivel *et al*., 2018).

2.6 Biodiesel from Various Non-edible Plant Oils

A review of existing research work on non-edible vegetable oil is important to select most suitable inedible source for biodiesel production. Recent studies on feedstocks show the advantageous perspective of selecting non-edible oil over edible vegetable oil.

According to many researchers, non-edible feedstocks could be exploited as a sustainable and alternative fuel (Atabani *et al*., 2013).

Based on existing information (previous studies), a review of non-edible feedstocks used for biodiesel production is presented as Table 2.1.

Table 2.1: List of various non-edible plants used for biodiesel production

Non-edible vegetable source	Distribution	Plant type	Plant part	Oil content		Yield of plant oils		Uses
				Seed (wt%)	Kernel (wt%)	Kg (oil/ha)	Liters (oil/ha)	
Azadirachta indica (Neem)	India (Native), Burma, Bangladesh, Sri Lanka, Malaysia Pakistan, Cuba, tropical and semitropical regions.	Tree	Seed, kernel	20–30	25–45	2670	–	Oil-illuminant, timber, firewood, biodiesel.
Aphanamixis piolystachya (wall.) Parker	India, China.	Tree	Kernel	–	35	–	–	Oil-illuminant.
Annona muricata	The Caribbean and Central America, available in tropical climates throughout the world.	Tree	Seed	–	20–30	–	–	Oil.
Annona squamosa	Caribbean, Central America, Northern South America, Western South America, Southern South America, Pacific, Australasia.	Tree	Seed	15–20	–	–	–	Oil, biodiesel.
Aleurites trisperma	Cuba	Tree	Kernel	–	–	–	–	Oil-illuminant.
Asclepias syriaca (Milkweed)	The northeast and north- central United States	Herbaceous, perennial	Seeds	20–25	0.019	–	–	
Barringtonia racemosa Roxb. (L.) Spreng.	East Africa (Widely distributed), Southeast Asia and the Pacific islands.	Tree	Seed	–	–	–	–	Oil-illuminant.

Source: Atabani *et al.*, 2013; Azam *et al.*, 2005; Bondioli *et al.*, 1998; Chakrabarti *et al.*, 2011; Chapagain *et al.*, 2009; Geller *et al.*, 1999; Hosamani *et al.*, 2009; Kimbonguila *et al.*, 2010; Laghetti*et al.*, 1995; Liu *et al.*, 2009; Martin *et al.*, 2010; Musman, 2010; Pinzi *et al.*, 2009; Ragit *et al.*, 2011; Ramadhas *et al.*, 2005; Sarin *et al.*, 2009; Wang *et al.*, 2011

Table 2.1, Continued.

Non-edible vegetable source	Distribution	Plant type	Plant part	Oil content		Yield of plant oils		Uses
				Seed (wt%)	Kernel (wt%)	Kg (oil/ha)	Liters (oil/ha)	
Brassica carinata (Ethiopian mustard)	Ethiopia	Herbaceous, annual	Seed, kernel	42	2.2–10.8		–	–
Balanites aegyptiaca (Desert date)	Growing in arid regions in Africa and Asia	Tree	Kernel		36–47	–	–	Oil, biodiesel.
Bombax malabaricum	India	Tree	Seed	18–26	–	–	–	
Calophyllum inophyllum L.	Tropical regions of India, Malaysia, Indonesia, and the Philippines.	Tree	Seed, kernel	65	22	4680	–	Oil used for burning, timber
Crambe abyssinica	Mediterania, Eithiopia, Tanzania, East of Africa, Italia, Argentina	Herb	Seed	30–38	–	1129	–	Oil, lubricant.
Ceiba pentandra	Native to Mexico, Central America and the Caribbean, northern South America, tropical west Africa, Indonesia (Java).	Tree	Seed	24–40	–	–	–	Timber, oil.
Cerbera odollam (Sea mango)	Native to India and other parts of Southern Asia	Tree	Seed, kernel	54	6.4	-	–	Illuminant (release thick smoke).
Croton tiglium	China, Malabar, Ceylon, Amboina (of the Molucca islands), the Philippines and Java	Herbaceous, perennial	Seed, kernel	30–45	50–60	–	–	Biodiesel, resin, oil.
Cuphea viscosissima	The eastern United States, North central USA to Argentina	Herbaceous, annual	Seed	20–38	–	900	–	Biodiesel
Crotalaria retusa L.	Native in Asia, Coastal Eastern and Africa	Herbaceous, annual	Seed	15	–	–	–	Oil, biodiesel.
Eruca sativa gars	Northwest of China, South Asia	Herbaceous, perennial	Seed	35	–	420–590	–	

Table 2.1, Continued.

Non-edible vegetable source	Distribution	Plant type	Plant part	Oil content		Yield of plant oils		Uses
				Seed (wt%)	Kernel (wt%)	Kg (oil/ha)	Liters (oil/ha)	
Garcinia indica	Tropical rain forests of Western Ghats, Konkana, North Kanara, South Kanara, Bombay, Goa. Cultivated in Ethiopia and India	Tree	Seed	45.5	–	–	–	Biodiesel, resin, oil.
Guizotia abyssinica		Herbaceous, annual	Seed	50–60	–	200–300	–	Commercial oil, biodiesel.
Hevea brasiliensis (Rubber)	Grows in Nigeria, India, Brazil, Southeast Asia, West Africa	Tree	Seed	40–60	40–50	50	–	Surface coatings including paints, printing inks, rubber/plastic processing, pharmaceuticals, lubricants, cosmetics, chemical intermediates and diesel fuel substitute.
Idesia polycarpa var.	The provinces to the south of Qinling mountain and Huaihe River in China	Tree	Fruit, seed	26.15 – 26.26	–	2250–3750	–	Oil, biodiesel.
Jatropha curcas L.	Indonesia, Thailand, Malaysia, Philipines, India, Pakistan, Nepal	Tree	Seed, kernel	20–60	40–60	1590	1892	Oil-illuminant lubricant, biodiesel.

Table 2.1, Continued.

Non-edible vegetable source	Distribution	Plant type	Plant part	Oil content		Yield of plant oils		Uses
				Seed (wt%)	Kernel (wt%)	Kg (oil/ha)	Liters (oil/ha)	
Linum usitatissimum (Linseed)	Distributed to the region extending from the eastern Mediterranean to India, wider cultivation of this crop in Europe and its adapted to wide range in Canada and Argentina	Herbaceous, annual	Seed	35–45	–	402	478	Oil for wall paint and floor oil, biodiesel, resin, fiber, surface coating applications stains, linoleum.
Madhuca indica	India	Tree	Seed, kernel	35–50	50	–	–	Biodiesel
Melia azedarach	Distributed to India, southern China and Australia	Shrub/ tree	Seed, kernel	10–45	2.8	–	–	Biodiesel
Michela chaampaca	Eastern Himalayas, Assam, Burma, China, Western Ghats and throughout India.	Tree	Seed	45	–	–	–	Oil, biodiesel.
Mesua ferrea	Forest in NorthEast India, Karnataka, Kerala		Seed	35–50	–	–	–	Soaps, lubricants, illumination.
Nicotiana tabacum (Tobacco)	Greece, Turkey, Bulgaria, Macedonia, India, England, Pakistan, Serbia, Brazil, Cuba,Columbia, East Africa, Ecuador, Fiji, Guatemala, Haiti, India, Iran, United States,Tanzania	Herb	Seed, kernel	36–41	17	2825	–	Oil, ethno-medicinal.

Table 2.1, Continued.

Non-edible vegetable source	Distribution	Plant type	Plant part	Oil content		Yield of plant oils		Uses
				Seed (wt%)	Kernel (wt%)	Kg (oil/ha)	Liters (oil/ha)	
Pongamia pinnata (Karanja)	Native Western Ghats in India, northern Australia, Fiji and in some regions of Eastern Asia.	Tree	Seed, kernel	25–50	30–50	900–9000	–	Oil-illuminant, timber, firewood.
Putranjiva roxburghii	Distributed in India	Tree	Seed	41–42	–	–	–	Oil-burning
Pongamia glabra (Koroch seed)	Naturally distributed in tropical and temperate Asia, from India to Japan to Thailand to Malesia to north and north-eastern Australia to some Pacific islands	Tree	Seed	33.6	–	225–2250	–	Oil for diesel generator, firewood.
Raphanus sativus	Widely grown and consumed throughout the world	Herbaceous, annual	Seed	40–45	–	–	–	
Ricinus communis (Castor)	Cuba, Brazil, China, India Italia, French and the countries of the former Sovien Union	Tree/shrub	Seed	45–50	–	1188	1413	Seed oil-fuel, Seeds yield castor oil, and used as cathartic and also for lubrication.
Simmondsia chinensis (Jojoba)	Mojave and Sonoran deserts of Mexico, California, and Arizona	Shrub	Seed	45–55	–	1528	1818	
Salvadora oleoides (Pilu)	Arid regions of Punjab (native), and West India	Tree	Seed	45	–	–	–	Seed is used candle making.
Sapium sebifeum L. Roxb (stillingia)	Native in China, Japan, India and grows well in the southern coastal United States	Tree	Seed, kernel	13–32	53–64	–	–	Fatty oil known as strillengia oil.

Table 2.1, Continued.

Non-edible vegetable source	Distribution	Plant type	Plant part	Oil content		Yield of plant oils		Uses
				Seed (wt%)	Kernel (wt%)	Kg (oil/ha)	Liters (oil/ha)	
Sleichera triguga (Kusum)	Distributed in the Himalayas, the western Deccan to Sri Lanka and Indo-China. It was probably introduced to Malesia and has naturalized in Indonesia (Java, the Lesser Sunda Islands (Bali and Nusa Tenggara), Sulawesi, the Moluccas, Ceram and the Kai Islands). It is occasionally cultivated throughout the tropics, especially in India	Tree	Seed	–	55–70	–	–	Fire-wood maker, excellent charcoal. a valuable component of true Macassar used in hairdressing, used for culinary lighting purpose, used in traditional medicine to cure itching, acne
Samadera indica	Indonesia, tropical region.	Tree	Seed	35	-	-	-	Oil
Sapindus mukorossi	Asia (India, Nepal), America, Europe.	Tree	Seed Kernel	851	-	-	-	Oil, Biodiesel.
Sapindus rarak (Soapnut)	Turkey, Greece, tropical and subtropical regions.	Tree	Seed	32- 37	-	5500	-	Oil, Soap manufacturing, fodder for cattles.
Vernicia fordii (Tung)	Southeast China	Tree	Seed	35- 40	-	790	940	Oil, Biodiesel
Terminala catappa	Brazil	Tree	Seed	49	-	200	-	Timber, Oil, Biodiesel.
Ximenia americana	Widely spread to India and south east Asia to Australia, New Zealand.	Tree	Kernel	-	49- 61	-	-	Oil, Lubricant.

2.7 Biodiesel Standards and Specifications

Biodiesel contains different physical and chemical properties from conventional diesel fuel. Various factors can influence biodiesel quality including feedstock quality, feedstock fatty acid composition, types of biodiesel production and employed refining process and post production parameters (Atabani *et al*., 2013). Therefore, a standard is required to control the biodiesel quality (Baskar & Aiswarya, 2016; Knothe, 2006). The standard is a way to protect both biodiesel producers and consumers as well as to support biodiesel industry development. All types of biodiesel fuel are required to fulfill international standard specification. Physical and chemical characteristics of biodiesel produced from a variety of sources (edible and non-edible) are described by these standards (Atabani *et al*., 2013).

Biodiesel standard is owned by many countries which is different in different countries. such as ASTM D6751 in the US, EN 14213 and 14214 in Europe. The US and EU standards are widely used as reference for the analysis of biodiesel standard (Knothe, 2006).

Based on USA, Europe and Germany standard, the biodiesel properties specification and its correlation with petroleum diesel is shown in Table 2.2 (Singh & Singh, 2010; Knothe, 2006; Singh *et al*., 2016; Thoai *et al*., 2017).

Table 2.2: Biodiesel specifications based on standards and its correlation with diesel

Properties	Unit	Europe EN 14214:2003 (FAME)	Germany DIN V 51606 (FAME)	USA ASTM D 6751-07b (FAME)	Petroleum diesel EN 590:1999 (Diesel)
Density at 15°C	g/cm³	0.86-0.90	0.875-0.90		0.82-0.845
Viscosity at 40°C	mm²/s	3.5-5.0	3.5-5.0	1.9-6.0	2.0-4.5
Distillation	% @ °C			90%,360°C	85%,350°C - 95%,360°C
Flash point	°C	120 (Minimum)	110 (Minimum)	93 (Minimum)	55 (Minimum)
CFPP	°C	* specific to country	summer 0 spr/aut - 10 winter -20		* specific tocountry
Cloud point	°C			* report	
Sulphur	mg/kg	10 (Maximum)	10 (Maximum)	15 (Maximum)	350 (Maximum)
CCR 100%	mass (%)		0.05 (Maximum)	0.05 (Maximum)	
Carbon residue (10%dist.residue)	mass (%)	0.3 (Maximum)	0.3 (Maximum)		0.3 (Maximum)
Sulphated ash	mass (%)	0.02 (Maximum)	0.03 (Maximum)	0.02 (Maximum)	
Oxid ash	mass (%)				0.1 (Maximum)
Water	mg/kg	500 (Maximum)	300 (Maximum)	500 (Maximum)	200 (Maximum)
Total contamination	mg/kg	24 (Maximum)	20 (Maximum)		24 (Maximum)
Cu corrosion max	3h/50°C	1	1	3	1
Oxidation stability	hrs;110°C	6 hours (Minimum)		3 hours (Minimum)	(25 g/m3) N/A
Cetane number		51(Minimum)	49 (Minimum)	47 (Minimum)	51 (Minimum)
Acid value	Mg KOH /g	0.5 (Maximum)	0.5 (Maximum)	0.5 (Maximum)	
Methanol	mass (%)	0.20 (Maximum)	0.3 (Maximum)	Fp <130°C or Maximum 0.2	

Source: Singh & Singh, 2010; Knothe, 2006; Singh *et al*., 2016; Thoai *et al*., 2017

Table 2.2, Continued.

Properties	Unit	Europe EN 14214:2003 (FAME)	Germany DIN V 51606 (FAME)	USA ASTM D 6751-07b (FAME)	Petroleum diesel EN 590:1999 (Diesel)
Ester content	mass (%)	96.5 (Minimum)			
Monoglyceride	mass (%)	0.8 (Maximum)	0.8 (Maximum)		
Diglyceride	mass (%)	0.2 (Maximum)	0.4 (Maximum)		
Triglyceride	mass (%)	0.2 (Maximum)	0.4 (Maximum)		
Free glycerol	mass (%)	0.02 (Maximum)	0.02 (Maximum)	0.02 (Maximum)	
Total glycerol	mass (%)	0.25 (Maximum)	0.25 (Maximum)	0.24 (Max)	
Iodine value		120 (Maximum)	115 (Maximum)		
Linolenic acid ME	mass (%)	12 (Maximum)			
C(x:4) & greater unsaturated esters	mass (%)	1 (Maximum)			
Phosphorus	mg/kg	10 (Maximum)	10 (Maximum)	10 (Maximum)	
Alkalinity	mg/kg		5 (Max)		
Group I metals (Na, K)	mg/kg	5 (Maximum)		5 (Maximum)	
Group II metals (Ca, Mg)	mg/kg	5 (Maximum)		5 (Maximum)	
PAHs	mass (%)				11 (Maximum)
Lubricity / wear	μm at 60°C				460 (Maximum)

CHAPTER 3: MATERIALS AND METHODS

3.1 Introduction

After conducting Focus Group Discussion (FGD), non-edible plants such as *Senna siamea* (cassia), *Albizia saman* (monkey pod), *Leucaena leucocephala* (lead), *Ceiba pentandra* (kapok), *Calotropis gigantea* (indian milkweed), *Annona muricata* (soursop), *Reutealis trisperma* (kemiri sunan), *Jatropha curcas* (physic nut), *Pongamia pinnata* (indian beech) and *Calophyllum inophyllum* (nyamplung) were chosen for this study to evaluate their potentiality as feedstock for biodiesel production. FGD was also conducted to select the criteria in the determination process of biodiesel producing plant priority.

A multi-criteria decision making tool, commonly known as Analytic Hierarchy Process (AHP) has been used to suggest the prior biodiesel producing plant. AHP analysis was done to analyze the structures of determination of biodiesel producing plant priority to get the importance values (weights) of each criterion, and to get final sequence of biodiesel producing plant priority.

The overall flow of methodology is shown in Figure 3.1.

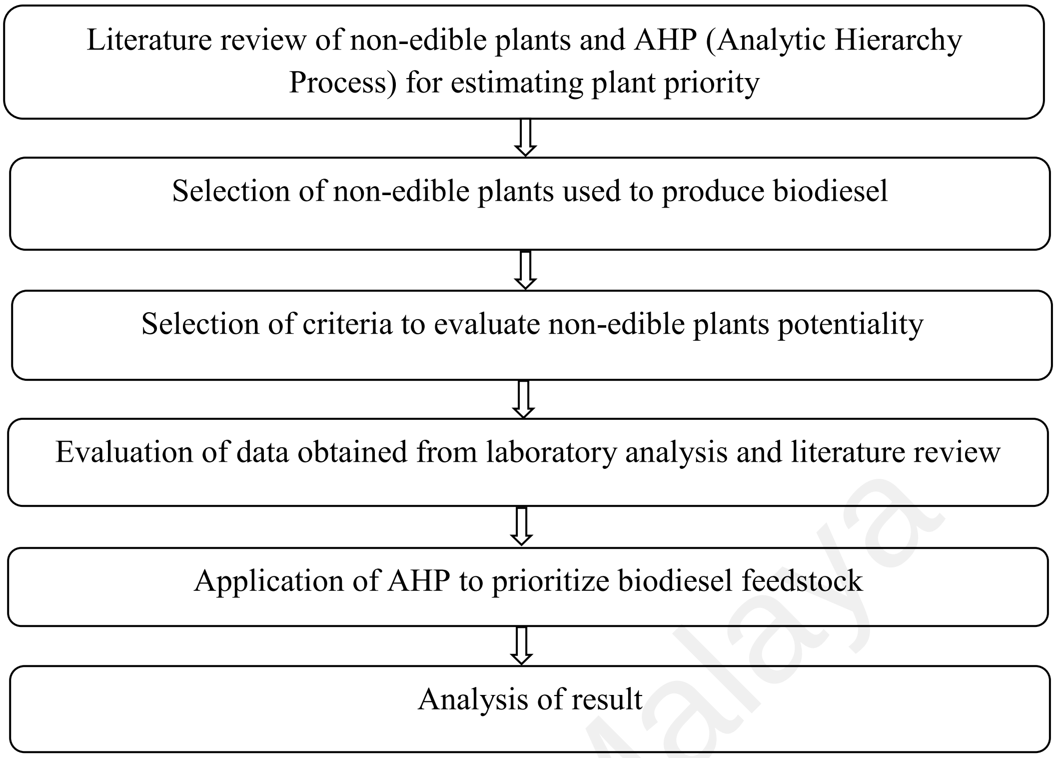


Figure 3.1: Overall flow of methodology

3.2 Focus Group Discussion (FGD)

FGD is a special type of interactive group discussion. Unlike one-on-one interview or group interview, Focus Group Discussion is a direct data collection method involving group interaction. It is considered as a better way to understand people opinion of an issue (Winke, 2017). It is also a popular method to collect large volume of data in relatively short time (Kraaijvanger *et al*., 2016).

During FGD, special type of group is gathered based on purpose, composition, size and procedure whose main purpose is to gather information and opinion regarding a particular topic. A facilitator introduces the topic to the participants and stimulates interaction among them (Schaafsma *et al*., 2017). The participants who are the experts of same field share their experiences, insights, perception and opinions regarding the concerned issue. Later on, gathered opinions from each participant are presented as a group opinion. It is assumed that, group interaction provide a level of validity of the generated data (Kraaijvanger *et al*., 2016).

FGD allows more flexibility in assessing individual beliefs, values and perceptions of an issue than other data collecting method. The results of the evaluation are also rich and innovative. However, the procedure requires careful result analysis to make the outcomes meaningful. Group interaction may also include conformance, coercion and conflict avoidance (Schaafsma *et al*., 2017).

In this study, a series of Focus Group Discussion (FGD) involving five experts (Dr. Mohd Radzi Abu Mansor, Dr. Mahendra Varman A/L Munusamy, Dr. Ong Hwai Chyuan, Dr. Pramila Tamunaidu, Dr. Chong Wen Tong) have been conducted to gather data in various aspects such as identification of biodiesel producing plant, determination of the criteria, assessments of the importance of each criterion as well as alternative plants in each determined criterion.

3.3 Criteria of Non-edible Plants

Seven criteria were chosen for this study based on importance of those criteria in evaluating the potentiality of biodiesel producing plant. These criteria included seed oil yield, free fatty acid (FFA) content, cold filter plugging point, oxidation stability, oil yield, easiness to grow in marginal land, as well as availability in tropical areas. Selection of these criteria has been done after literature review and Focus Group Discussion (FGD). A brief discussion of the criteria is given in this section.

3.3.1 Free Fatty Acid (FFA) Content

As fatty acid composition is the indicator of efficiency process of biodiesel production, it is considered as important property of any biodiesel raw material (Atabani *et al*., 2013). The composition of the fatty acid portion of the biodiesel ester molecule varies according to different feedstock which is the most important factor to affect its properties (Yaakob *et al*., 2014). Feedstocks may vary in the amount of fatty acids while commonly found fatty acids are C_{16} and C_{18} (Barma *et al*., 2012). According to Bouaid *et al*. (2016), free fatty acid content can influence biodiesel purity and yield as well. They also observed that, methyl ester yield is decreased (97.2%- 95%) with an increase in the FFA content of the oil (0%- 4%).

3.3.2 Cold Filter Plugging Point

Cold filter plugging point (CFFP) is the indication of fuel operability at low temperature. It also refers the temperature at which plugging of test filter start because of crystalized fuel components. Moreover, it also indicates the filterability limit of the fuel namely biodiesel and petro-diesel (Atabani *et al*., 2013).

3.3.3 Oxidation Stability

When fuel properties are concerned, oxidation stability is considered as one of the important criteria of fuel (biodiesel and petro-diesel). Generally, the stability of diesel fuel is higher than biodiesel. During long term storage of biodiesel fuel, the formation of contaminants (peroxides, acids, alcohols, aldehydes) leads to the darkening of the fuel. The contaminants are also the reason of the formation of deposits and gum. Among different processes, one of the important stability concerns is oxidation associated with biodiesel as it may be affected by air oxidation easily due to lower resistance capacity (Yaakob *et al*., 2014).

3.3.4 Easiness to Grow in Marginal Land

Marginal land can be defined in various ways in different disciplines. Marginal land includes wasteland and winter-fallowed paddy land that can be used to produce energy crops whereas marginal land can be scrubland, natural grassland, unused land, unfertilized land and sparse forestland (Fu *et al*., 2014)

It is one of the important criteria of bioenergy crop development which is considered as an efficient way to deal with present energy crisis. Energy crops have the ability to grow on abandoned land. An analysis conducted by Fu *et al*. (2014), showed the potentiality of bioenergy crop production in marginal land. According to them, the utilization of marginal land could affect the gross biofuel production of a country.

3.3.5 Plant Availability in Tropical Areas

Besides, arid, semi-arid regions, non-edible plants can grow in tropical areas. Growing capacity of plants in various habitats makes it an efficient candidate to be used in commercial purpose as it reflects easy availability.

3.3.6 Seed Oil Yield (wt %)

It is the calculation of oil content of seed by its weight. When the cultivation of plants for biofuel production is concerned, growing oilseed crop which contains high oil content of best quality is the ultimate purpose of a crop cultivator.

3.3.7 Oil Yield (Kg/ha)

Seed oil yield and seed yield of a crop plant varies according to the variety. Both seed yield and seed oil content are combined together to express oil yield of a crop plant (Sana *et al*., 2003). As it indicates suitability of a plant to be used for biodiesel production, the criteria is an important criteria to be evaluated when selecting the most preferred feedstock.

3.4 Non-edible Plants

3.4.1 Selection Method of Non-edible Plants

The non-edible plants that can be used to produce biodiesel were determined by using Analytic Hierarchy Process (AHP) method. Seven criteria have been considered in the determination of the inedible plants. These criteria included seed oil yield, free fatty acid (FFA) content, cold filter plugging point, oxidation stability, oil yield, easiness to grow in marginal land, as well as availability in tropical areas. Three stages were followed while evaluating the selected plants. The first stage of hierarchy was the selection of potential biodiesel plants. Subsequently, the second stage involved the consideration of criteria which were used to select the potential plants and the alternatives (non-edible plants) selection was the third stage. This plant selection hierarchy is depicted in Figure 3.2.

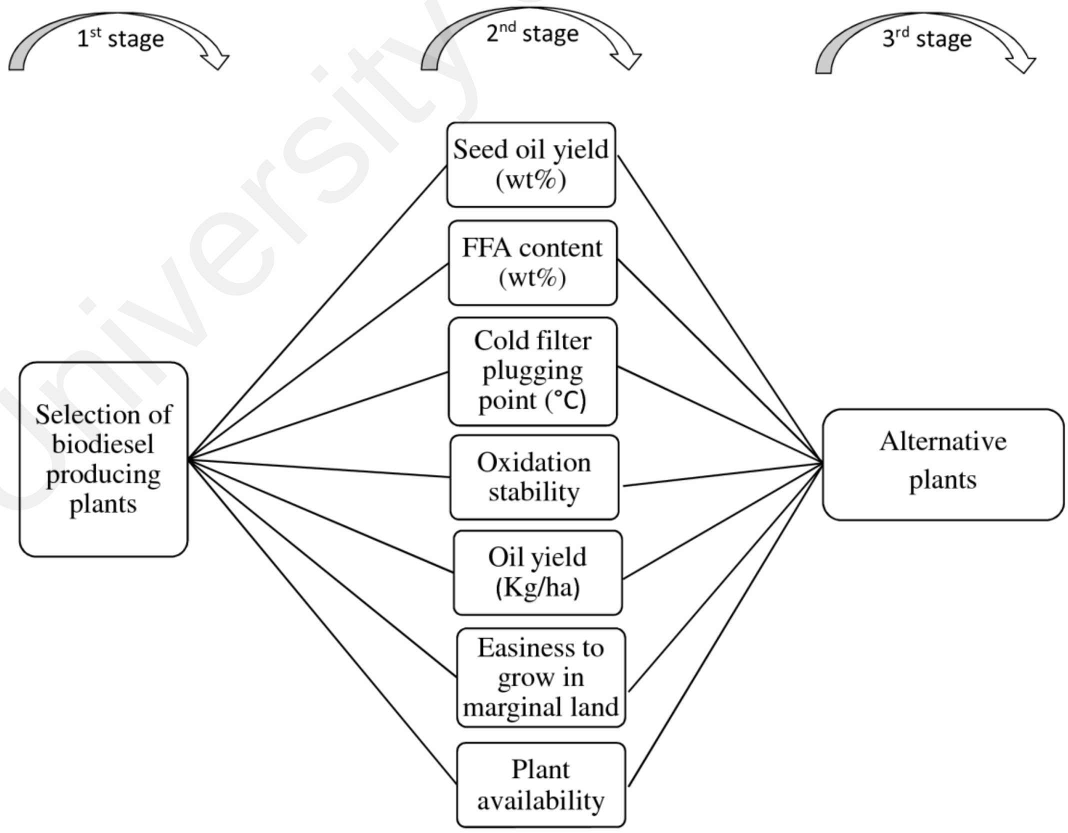


Figure 3.2: Hierarchy of alternative plant selection

3.4.2 Biodiesel Producing Plants (Alternatives)

According to the experts involved in Focus Group Discussion (FGD), ten non-edible oil producing plants (available in South-East-Asian region including Malaysia) were chosen for this study. Introduction of all the selected plants is given as Table 3.2 and a brief discussion is given as follows.

3.4.2.1 *Calophyllum inophyllum* (nyamplung)

Nyamplung is a multipurpose tree which which is commonly familiar as penaga laut in Malaysia and nyamplung worldwide. It belongs to clusiaceae family (Ong *et al*., 2011). Having a wide range of origins, it is available in tropical areas, eastern Africa, southern coastal India, Southeast Asia, Australia, the South Pacific, Madagascar, Papua New Guinea, tropical America (west and east coast of Peninsula), Polynesia and Melanesia, and tropics of Asia (mainly Indo-Malaysian region and Ceylon) (Arumugam & Ponnusami, 2019; Ong *et al*., 2011; Azad *et al*., 2016; Atabani & César, 2014).

Traditionally, the oil extracted from the plant seed has been used in various purposes such as soap, hair grease, cosmetics, medicine and lamp oil in different parts of the world (Demirbas *et al*., 2016). Now it is considered that, nyamplung has big potential to be used as a biodiesel feedstock because of its high seed oil content (Fadhlullaha *et al*., 2015), high survival potency in nature, easiness to grow in marginal land, not competing with food crops as well as low plantation cost (Azad *et al*., 2016). The seed oil content is 51.2% (weight basis) having higher productivity or oil yield of 2000 (kg/ha). In addition, it has high oxidation stability, cold filter plugging point, and FFA content which are 8.5 h, -2°C and 20 (wt%) respectively (Zakaria *et al*., 2014).

3.4.2.2 *Albizia saman* (monkey pod)

Monkey pod is a species of the pea family or fabaceae. Its distribution ranges from Mexico south to Peru, Brazil, India and tropical areas as well. This wide-canopied tree is named 'rain tree' and 'five o'clock tree' due to folding of the leaves during rainy weather and in the evening (Manjunathan *et al*., 2016).

The oil content of monkey pod is 180 kg/ha while its seed oil yield is 4.7% of its weight. Although, it has higher oxidation stability (6.5 h) and cold filter plugging point (-1°C), it has lower free fatty acid content (2% of weight). However, easiness to grow in marginal land as well as wide availability in tropical areas have been considered as important characteristics of this plant to be used as biodiesel feedstock (Phoo *et al*., 2013)

3.4.2.3 *Reutealis trisperma* (kemiri sunan)

The plant is known as philippine tung, which belongs to the euphorbiaceae family (Riayatsyah *et al*., 2017). Though many Asian countries such as Philiphines, Indonesia and Malaysia cultivate kemiri sunan in small scale, it is native to Philiphines (Manurung *et al*., 2016).

Lots of non-edible fruits containing seeds inside the shells are found in this tree. According to Supriyadi *et al*. (2018), high oil content of seeds is the major advantage of this plant which makes it a competitive feedstock for biodiesel production. Its oil yield is 5500 kg/ha and oil content of seed is 40.2 % of its weight. Its oxidation stability is 7 h while cold filter plugging point and FFA content are respectively -1°C and 7(wt%) (Phoo *et al*., 2013). In addition, it has specific oil characteristics, relatively rapid growth, wide distribution in tropical areas, easy growing capacity in marginal land as well as suitability for land conservation (Supriyadi *et al*., 2018).

3.4.2.4 *Calotropis gigantean* (indian milkweed)

Swallow-wort or indian milkweed is the common name of this plant. It belongs to the family asclepiadaceae (Holser & Harry-O'Kuru, 2006). Though it is native to China, India and Malaysia, it has a wide distribution in tropical areas mostly in Asia, Africa and South America (Kumar *et al*., 2013; Phoo *et al*., 2014).

The growing capacity of this plant in different kind of soils including marginal land as well as different climates makes it as a potential candidate of biodiesel feedstock. Sometimes it is considered as a weed because of its easy growing capacity and too much biomass generation (Chamuah *et al*., 2013; Eapen *et al*., 2006). In addition, flowering and fruiting take place throughout the year (Phoo *et al*., 2014). Furthermore, the seeds of the plant contain 33.3% oil of its weight having oil productivity of 500kg/ha. Though, it has higher FFA content (28 wt%), it has lower cold filter plugging point (8°C) and oxidation stability(1.4 h) (Phoo *et al*., 2013; Phoo *et al*., 2014). Moreover, not competing with the food supply are the major benefits of using this plant as a biodiesel feedstock.

3.4.2.5 *Ceiba pentandra* (kapok)

Silk cotton tree or kapok is the common name of this plant which belongs to malvaceae family (Kusumo *et al*., 2017). Its availability ranges from tropical America to West Africa and Asia including Malaysia, Indonesia, Vietnam, Philippines, India and Pakistan (Silitonga *et al*., 2013).

It is a drought resistant tree and can grow in marginal land. Kusumo *et al*. (2017) observed that the seeds of the plant contain relatively high non-edible oil content which makes it an efficient source of biodiesel. The oil content of seeds is about 23.1(wt %) with oil yield 450 kg/ha. Its FFA content, cold filter plugging point and oxidation stability are respectively 15 (wt %), -4°C and 0.8 h (Phoo *et al*., 2013). In addition, Its biodiesel-diesel blends was proven to give good engine performance and reduced carbon monoxide and smoke density which add environmental benefit as well (Kumar *et al*., 2015; Silitonga *et al*., 2013). According to Silitonga *et al*., (2013), the fuel blend containing 90% diesel and 10% *Ceiba pentandra* biodiesel gives the highest brakespecific fuel consumption (BSFC), engine torque and brake power (Dharma *et al*., 2017).

3.4.2.6 *Jatropha curcas* (physic nut)

Purging nut or physic nut is a multipurpose deciduous small tree or shrub, belongs to euphorbiaceae family (Kumar & Das, 2018). In this era, the plant has pan-tropical, tropical and sub-tropical distribution, though it was originated in South America such as Brazil, Mexico, Paraguay, Peru, Central America, Bolivia (Kumar & Das, 2018).

Among the inedible oil sources, this plant has gained tremendous importance as it can adapt easily in the arid and semiarid conditions, can grow on eroded, degraded, saline and sodic soils, pest resistant, drought tolerant, and produces seeds early (Naresh *et al*., 2012; Atabani *et al*., 2013). Moreover, it meets prerequisites of biodiesel producing plant such as high oil yield and seed oil content (Kumar & Das, 2018). The oil productivity of this plant is 2800 kg/ha with a high seed oil yield (45 wt %). Free fatty acid (FFA) content of the oil is 14 (wt %). The oxidation stability and cold filter plugging point of the fuel produced from physic nut seed oil is 6.7 h and -2.5°C respectively (Phoo *et al*., 2013; Ilham & Saka, 2010). Moreover, low water and nutrient requirement make it most popular plant for biodiesel production (Kumar *et al*., 2016) while growing capacity on marginal land and chemical properties add more advantages (Castillo *et al*., 2014). Apart from supplying oils for the replacement of conventional diesel, the tree itself reduces CO_2 concentrations effectively in the atmosphere (Karmakar *et al*., 2010; Silitonga *et al*., 2013)

3.4.2.7 *Leucaena leucocephala* (lead)

It is a leguminous fast growing tree, predominantly populates in Mexico and Central America but now it is naturalized in most of the tropical and sub-tropical regions around the world. It belongs to the fabaceae family (Devi *et al*., 2013). In general, it is known by the indigenous as subabul in India, ipil-ipil in the Philippines, yin hue in China and petai belalang in Malaysia (Hakimi *et al*., 2017).

The advantages of using the plant in biodiesel industry is its capacity to grow in marginal land very easily and high oil yield (3000 kg/ha). The oil content of seed is 4.2% of its weight. It has lower FFA content (6%), cold filter plugging point (20°C), and oxidation stability (1.7 h) (Phoo *et al*., 2013; Ramli & Ilham, 2017; Ilham *et al*., 2015). In addition, its seed oil is inedible due to the existence of mimosine, a toxic amino acid to non-ruminant vertebrates which reduces food vs. fuel conflict (Ilham *et al*., 2015).

3.4.2.8 *Pongamia pinnata* (indian beech)

Suryawanshi & Mohanty, (2018) reported a thick, bitter, red brown, non-edible, non-drying oil, known as karanja oil from the seeds of *Pongamia pinnata*.The plant belongs to the fabaceae family which is familiar as *Millettia pinnata*, honge, karanja, and indian beech (Arpiwi *et al*., 2017; Suryawanshi & Mohanty, 2018). The plant can survive in adverse condition such as drought, frost, heat, limestone, sand, and salinity (Rajakokila *et al*., 2017; Karmakar *et al*., 2010).

During the past decade, the plant has been used in some countries mostly Asian as a source of traditional medicine, timber, animal fodder, pesticides, green manure and fish poison (Atabani *et al*., 2013). Now it is recognized as a potential non-edible source for burgeoning biodiesel industry (Atabani *et al*., 2013). According to Suryawanshi & Mohanty (2018), the oil is eco-friendly, biodegradable and one of the best alternatives to petrochemicals. The plant has a productivity of 2300 kg/ha oil while seed oil yield is 39.2 % of its weight. It can grow in marginal land easily. The oxidation stability of the fuel is 4.5h. FFA content and cold filter plugging point are respectively 3 (wt%) and -3°C (Phoo *et al*., 2013; Goembira & Saka, 2015).

The advantages of using this plant oil for biodiesel production include high quality of oil, no direct competition with food, nitrogen fixing capacity from the soil, and minimizing the need of fertilizers.

3.4.2.9 *Senna siamea* (cassia)

It is a fast growing and one of the highest biomass producing plants which belongs to the family fabaceae (Mund *et al*., 2016). This species has distribution in arid regions mostly in West Africa and has been very useful in afforestation program using marginal land (Parveen *et al*., 2010). It can also be found in tropical areas. The leaves of this plant are used as fodder and green manure whereas the wood is mostly as fuel-wood. Since the plant produces 280 kg/ha oil having seed oil content of 5.4 (wt %), it is reported to be used as a biodiesel feedstock. Its FFA content is 17 (wt %). The fuel has oxidation stability of 3.9 h and cold filter plugging point is 4°C (Phoo *et al*., 2013).

3.4.2.10 *Annona muricata* (soursop)

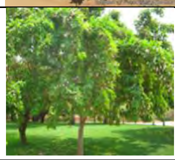
It is a broadleaf, flowering, and evergreen tree which is widely known as soursop has emerged as a potential feedstock for biodiesel production (Okoro & Kusin, 2013; Pinto *et al*., 2018; Folorunsho *et al*., 2014). It is native to Mexico, the Caribbean, northern South America, Cuba, Central America, Ecuador, Colombia, Peru, Venezuela, Brazil, as well as in some parts of Africa, the Pacific and Southeast Asia (Adepoju *et al*., 2014). The plant can grow in marginal land (Phoo *et al*., 2013). It is reported that the plant seed is rich in oil and can be exploited in the oil industry. The seed contains 20.5% oil of its weight having oil yield of 300 kg/ha. The FFA content (4 wt %) and oxidation stability (0.6 h) are lower in the fuel whereas it has good cold filter plugging point (-1°C) (Phoo *et al*., 2013).

The description summary of all the criteria is presented as Table 3.1

Table 3.1: Criteria assessment of the non-edible plants

	Criteria evaluation						
Plants name	Seed oil yield (wt%)	FFA content (wt%)	Cold filter plugging point (°C)	Oxidation stability (h)	Oil yield (Kg/ha)	Easiness to grow in marginal land	Plant availability in tropical areas
Senna siamea (Cassia)	5.4	17	4	3.9	280	Easy	Medium
Ceiba pentandra (Kapok)	23.1	15	-4	0.8	450	Medium	Medium
Leucaena leucocephala (Lead)	4.2	6	20	1.7	3000	Very Easy	Wide
Albizia saman (Monkey pod)	4.7	2	-1	6.5	180	Medium	Wide
Calotropis gigantean (Indian milkweed)	33.3	28	8	1.4	500	Medium	Wide
Annona muricata (Soursop)	20.5	4	-1	0.6	300	Medium	Medium
Pongamia pinnata (Indian beech)	39.2	3	-3	4.5	2300	Easy	Medium
Jatropha curcas (Physic nut)	45.0	14	-2.5	6.7	2800	Very Easy	Medium
Reutealis trisperma (Kemiri sunan)	40.2	7	-1	7	5500	Easy	Wide
Calophyllum inophyllum (Nyamplung)	51.2	20	-2	8.5	2000	Easy	Wide

Table 3.2: Non-edible plants with properties

Plants name	Plant	Fruit	seed
Senna siamea (Cassia)			
Albizia saman (Monkey pod)			
Leucaena leucocephala (Lead)			
Ceiba pentandra (Kapok)			
Calotropis gigantea (Indian milkweed)			
Annona muricata (Soursop)			
Reutealiss trisperma (Kemiri sunan)			
Jatropha curcas (Physic nut)			
Pongamia pinnata (Indian beech)			
Calophyllum inophyllum (Nyamplung)			

3.5 AHP (Analytic Hierarchy Process)

Multi-criteria decision making (MCDM) is an approach to evaluate multiple conflicting criteria explicitly in the discrete decision spaces. It is a way to determine the best one among various alternatives. In a MCDM problem, various alternatives are evaluated based upon preference and priorities of decision maker. In literature a number of MCDM approaches are found such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Analytic Hierarchy Process (AHP), Multi Attribute Utility Technique (MAUT) and Analytic Network Process (ANP) (Ozdemir & Sahin, 2018). Among all other methods, Analytic Hierarchy Process (AHP) has been considered as the most suitable approach to be used in resource management, corporate policy and strategy, public policy, political strategy, and planning (Velasquez & Hester, 2013). In this study, AHP has been successfully used in ordering selected non-edible plants based on preference.

Analytic Hierarchy Process (AHP) is an effective tool to deal with complex decision which was developed by Saaty (1980) with an aim to aid decision maker to make best decision by setting priorities. AHP is helpful to cover both the objective and subjective aspect of a complex decision by reducing it into pairwise comparisons which synthesize the result. In addition, AHP consist a technique to check consistency of decision maker's evaluation and thus reduce the scope to be biased (Saaty, 1980; Albayrak & Erensal, 2004).

Analytic Hierarchy Process (AHP) analysis is carried out by following two main phases namely hierarchy design and evaluation where hierarchy is designed based on knowledge and experience of decision maker on a particular area (Abdel-malak *et al*., 2017; Vaidya & Kumar, 2006). AHP consist a multi-level hierarchical structure which is the composition of objectives, criteria, sub-criteria, and alternatives. A set of pairwise comparisons are done to obtain data whereas the comparisons are used to get importance weight of the criteria as well as priority vector of the alternatives in term of each selected criterion (Saaty, 1980, 2008).

The basic steps of AHP method are summarized as figure 3.3.

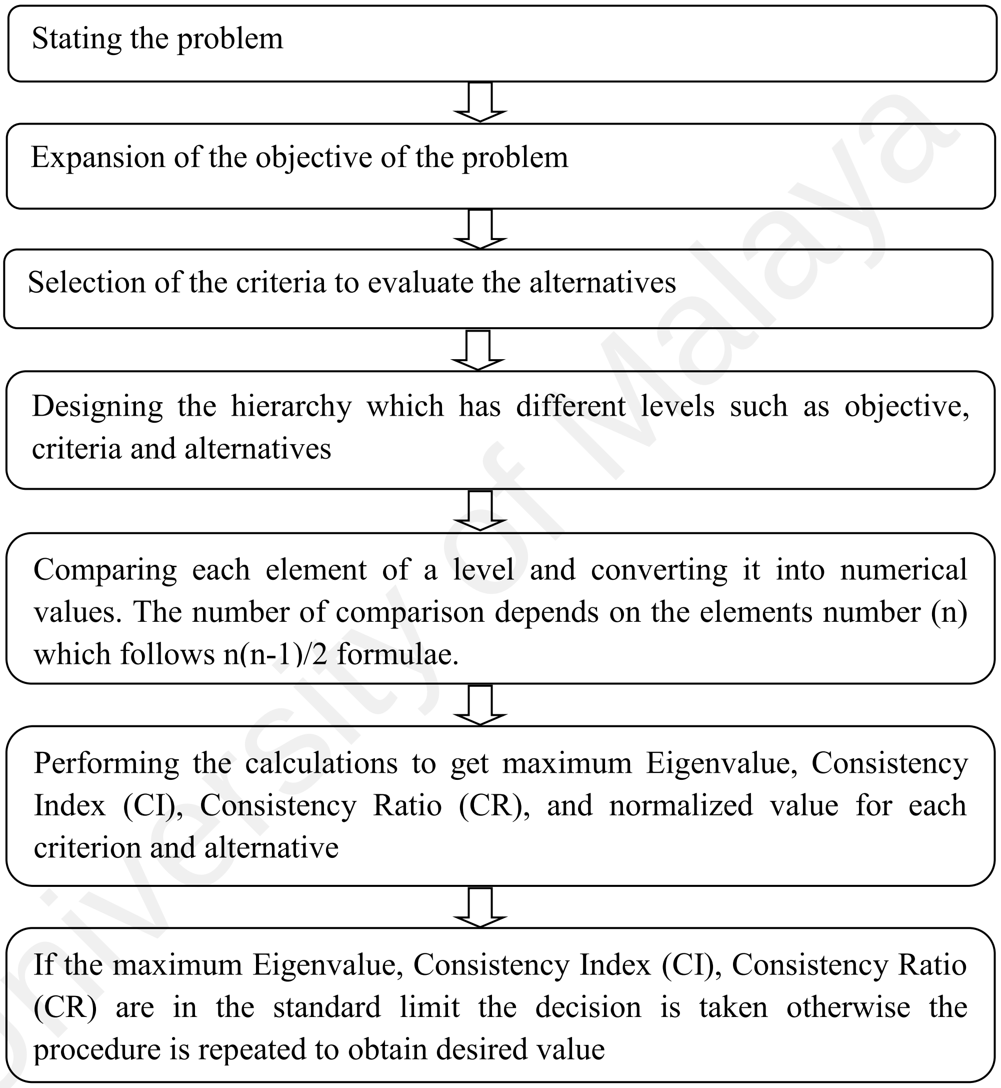


Figure 3.3: Basic steps of AHP (Vaidya & Kumar, 2006; Abdel-malak *et al.*, 2017).

Being a practical methodology, AHP helps decision makers in determining their preferences to achieve the objective. It involves a structure which simplifies the complicated problem. AHP allows integration of both objective and subjective as well as quantitative and qualitative information into the decision procedure. A decision maker can also analyze flexibility of final decision through sensitivity analysis during AHP calculation. The method also includes a step to check degree of consistency of decision maker judgments (Okudan & Tauhid, 2008; Vaidya & Kumar, 2006; Abdel-malak *et al*., 2017).

AHP has various application including making choice while multiple decision criteria are involved and it can also determine relative importance of members of alternative set. The important aspect of using AHP is conflict resolution while the improvement of quality is another one.

There are certain criticisms of AHP regarding its theory and practice. Rank reversal is one of the major limitations of AHP as the rank of an alternative changes when a new alternative is added or removed. Subjective nature of the process is also considered as a drawback which means the procedure cannot guarantee the ultimate true decision. AHP procedure is time consuming and require more effort if it involves a large number of criteria or alternatives. Moreover, the theory is regarded as insufficient when there is a need to deal with a lot of information such as sub-criteria of each criterion (Arroyo *et al*., 2015; Okudan & Tauhid, 2008; Abdel-malak *et al*., 2017).

3.5.1 Steps of AHP

In AHP, a hierarchy of sub-problem is constructed by decomposing a problem which can be evaluated subjectively and understood easily. After converting subjective evaluations into numerical values, each alternative is ranked numerically. The AHP method is mainly composed of four steps namely a) structuring the hierarchy, b) pairwise comparisons of criteria and alternatives c) synthesis of the priorities and d) consistency check (Albayrak &Erensal, 2004; Saaty, 2008).

3.5.1.1 Structuring the Hierarchy

A hierarchy, fundamental of AHP, is structured by breaking down a complex multi-criteria decision problem into interrelating decision elements (goal, criteria and alternatives). Hierarchy shows the relationship among different level of the hierarchy. The relationship percolates down to the lower level presenting the connection of one element with every other element (direct or indirect) (Albayrak & Erensal, 2004; Dağdeviren *et al*., 2009). In this study, a hierarchy has been constructed having three levels: the top level is the objective to be achieved, the middle level is consists of the criteria which influence the goal as well as used to evaluate alternatives and the alternatives at the bottom level (Figure 3.4).

3.5.1.2 Comparative Judgment of the Criteria and Alternatives

The AHP computation was done based on pairwise comparison matrix which gives the relative importance of each element of the hierarchy with respect to the objective. The pairwise comparisons were done for both the criteria and alternatives. After decomposing the problem into the hierarchy, prioritization procedure starts. Determination of relative importance was done from the second level (criteria) to third level (alternatives).

The judgment or comparison between two elements is considered as the numerical representation of their relationship sharing a common parent. At first, the pairwise comparisons of criteriawere done and then it was followed by the alternatives. During AHP multiple pairwise comparisons, a standard scale of comparison consisting nine levels was used to express degree of preference of one element over another (Table 3.3) (Albayrak &Erensal, 2004; Saaty, 2008).

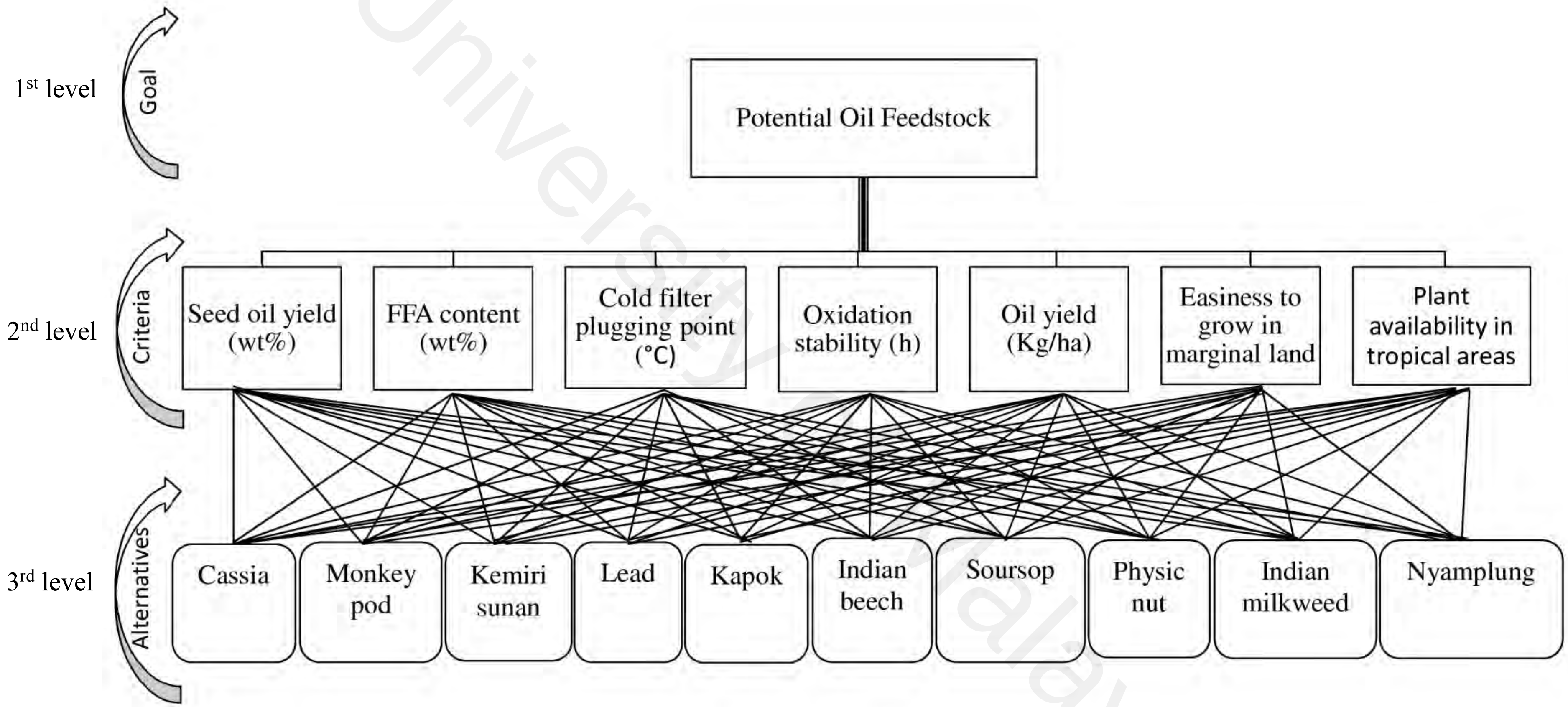


Figure 3.4: AHP Hierarchy

Table 3.3: Standard scale of AHP

Importance value	Degree of preference	Explanation
1	Equally important	Two elements have equal contribution to the objective.
3	Moderately important	One element is slightly favored over another element.
5	Strongly important	One element is strongly favored over another.
7	Very strongly important	One element favor very strongly over another toward objective.
9	Extremely important	One element is favored to the highest possible order over another.
Intermediate values are expressed by the values 2, 4, 6, and 8 whereas the elements with very close in importance are expressed by the values 1.1, 1.2, 1.3, etc.		

Source: Albayrak & Erensal, 2004; Saaty, 2008)

The length of pairwise comparison matrix is equivalent to the number of criteria used in decision making process. As this study involves seven criteria, the comparison matrix was 7/7 matrix and same procedure was followed for alternatives. The value in pairwise comparison matrix was determined by Focus Group Discussion (FGD).

3.5.1.3 Synthesis of the Priorities

The data obtained from pairwise comparisons were organized in a matrix form as well as summarized according to Saaty's eigenvector method. The pairwise comparison data were converted into numerical values and the normalized weight vector (w) was obtained by solving following equation (Eq. 1, 2) (Albayrak & Erensal, 2004; Morteza*et al*., 2016)

$$Aw = \lambda max\ w \quad \ldots\ldots\ldots\ldots (1)$$

$$w = (w_1, w_2, w_3, \ldots\ldots, w_n) \quad \ldots\ldots\ldots\ldots (2)$$

Here, A is the pairwise comparison matrix, w is the weight vector (normalized), λmax is the maximum eigenvalue of the matrix A.

Maximum eigenvalue (λmax) was calculated by the equation 3.

$$\lambda max = \sum_{j=1}^{n} \left(a_{ij} \frac{w_j}{w_i}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

In equation 3, the result shows a positive reciprocal matrix A= $\{a_{ij}\}$ with $a_{ji} = \frac{1}{a_{ij}}$. Here, a_{ij} isthe representation of numerical equivalence of the comparison between two criteria (criterion i and criterion j (Albayrak & Erensal, 2004)

In case of complete consistency of pairwise comparisons, the matix A hold the rank 1 and λmax = n. In this scenario, normalization of any of the rows or columns of A could be done to obtain weights (Bitarafan *et al.*, 2016)

The final stage of AHP calculation is the determination of Overall Priority Vector (OPV). The OPV was obtained by summing the product of the priority vector of alternative and the criteria weight, with respect to that criterion. The Overall Priority Vector presents the overall ranking of alternatives with respect to the objective (Albayrak & Erensal, 2004).

3.5.1.4 Consistency Check

The result quality is determined by assessing the consistency of the pairwise comparisons and the relation between the entries of A which can be expressed as equation 4. Such as:

$$A: aij \times ajk = aik \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

As the comparisons are subjective in this method, AHP result might contain inconsistency because of the redundancy. If the consistency is higher than standard level the assessment or comparisons might be re-examined (Saaty, 2008).The Consistency Index (CI) has been calculated by using following equation (Eq. 5).

$$CI = \frac{(\lambda max - n)}{(n-1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The Consistency Ratio (CR), based on which a decision maker can conclude whether the consistency of the assessment is sufficient or not, was calculated as a ratio of Random Index (RI) (Table 3.4) and Consistency Index (CI) (Eq. 6) (Albayrak & Erensal, 2004).

$$CR = CI/RI \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Consistency Ratio has been calculated carefully as the standard maximum value of CR is 0.1. If the CR value exceeds the standard limit, the whole evaluation procedure must be repeated. It is useful in evaluating the consistency of decision makers as well as the hierarchy (Albayrak & Erensal, 2004; Saaty, 2008).

Table 3.4: Random Index (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Li *et al*., 2018

CHAPTER 4: RESULT AND DISCUSSION

4.1 Introduction

The chapter contains the result of the study and discussion over it. It is divided into four sections. The first section includes determination of importance weight of the criteria whereas second part is consists of the determination procedure of priority vector of the plants. At last, determination of prior biodiesel feedstock is discussed in the third section.

4.2 Determination of Importance Weight of the Criteria

The importance value of the criteria was determined by following pairwise comparison matrix method. The assessment regarding the importance weight of criteria is presented as pairwise comparison matrix in Table 4.1. Results obtained from pairwise comparison matrix are given in Table 4.2.

According to the result of AHP computation on the importance weight of the criteria, seed oil yield (wt %) was the criterion with highest influence in determining biodiesel producing plant priority. On the other hand, the criterion with least influence was the availability of the plants in tropical areas. The result obtained as criteria weight is listed from the highest to the lowest as follows: seed oil yield (0.3002), oil yield (0.2817), FFA content (0.1664), cold filter plugging point (0.0899), oxidation stability (0.0865), easiness to grow in marginal land (0.0463), andavailability in tropical areas (0.0289) (Table 4.2). The graphical representation is given as Figure 4.1.

Consistency Ratio (CR), ratio of Consistency Index (CI) and the Random Index (RI), was calculated to check whether judgment on the importance value of each criterion was correct or not. Consistency Ratio was found 0.025. Since, CR= 0.025 ≤

0.1(standard value), it is assumed that, the judgment on the importance value is considerably consistent.

Table 4.1: Pairwise comparison matrix of criteria

	Seed oil yield (wt%)	Oil yield (Kg/ha)	FFA content (wt%)	Cold filter pluggin g point (°C)	Oxidation stability (h)	Easiness to grow in marginal land	Availability in tropical areas
Seed oil yield (wt %)	1	1	2	3	4	7	9
Oil yield (Kg/ha)	1	1	2	3	3	6	9
FFA content (wt %)	0.5	0.5	1	2	2	4	6
Cold filter plugging point (°C)	0.33	0.33	0.5	1	1	2	3
Oxidation stability (h)	0.25	0.33	0.5	1	1	2	3
Easiness to grow in marginal land	0.14	0.17	0.25	0.5	0.5	1	2
Availability in tropical areas	0.11	0.11	0.17	0.33	0.33	0.5	1

Table 4.2: Results obtained from AHP computations for criteria

Criteria	Criteria weight	Criteria weight (%)	Priority rank	λmax, CI, RI	CR
Seed oil yield (wt%)	0.3002	30.1%	1	λmax = 7.02 CI = 0.033 RI = 1.32	0.025
Oil yield (Kg/ha)	0.2817	28.2%	2		
FFA content	0.1664	16.6%	3		
Cold filter plugging point	0.0899	9.0%	4		
Oxidation stability	0.0865	8.6%	5		
Easiness to grow in marginal land	0.0463	4.6%	6		
Availability in tropical areas	0.0289	2.9%	7		

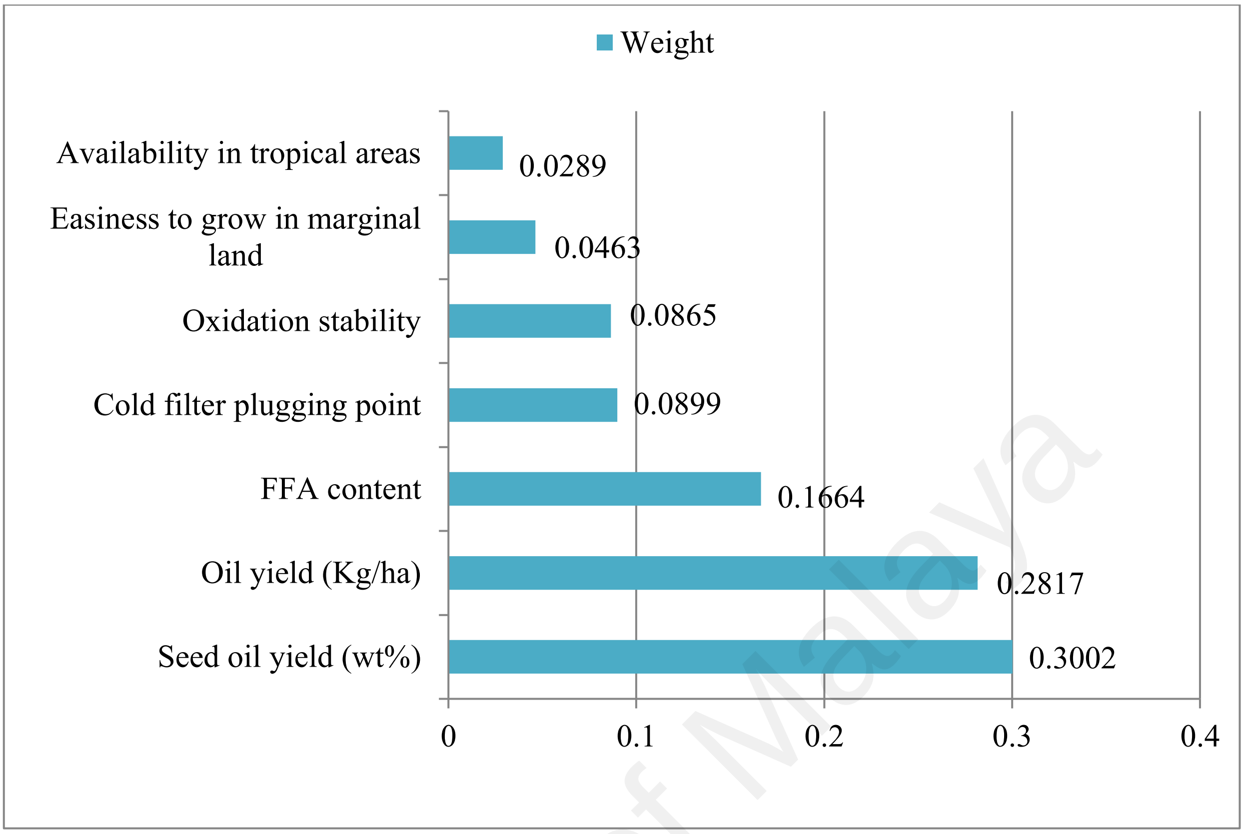


Figure 4.1: Result of criteria weighting

4.3 Determination of Priority Vector of Non-edible Plants

The pairwise comparison matrix was conducted for all the criteria to determine priority vector of non-edible plants. The priority vector is the representation of the importance of the non-edible plants regarding the criteria. The pairwise comparison matrix and the result from AHP computations are described in this section.

4.3.1 Seed Oil Yield (wt %)

The pairwise comparison matrix of the seed oil yield criterion and the result obtained from AHP computation are presented as Table 4.3 and Table 4.4 respectively. According the result of AHP calculation, nyamplung holds the first position having highest priority vector (0.266743) followed by the other plants. Fadhlullaha *et al*. (2015) considered nyamplung as a potential biodiesel feedstock because of its high seed oil yield. On the other hand, lead is the least preferred choice with priority vector 0.029114. As physic nut and kemiri sunan have same priority vector (0.154008), these are interchangeable in case of choosing the best plant oil for biodiesel production. The same trends are observed between kapok and soursop and cassia and monkey pod.

4.3.2 Oil Yield (Kg/ha)

The pairwise comparison matrix of the oil yield criterion is depicted as Table 4.5 and the result is shown in Table 4.6. AHP results show that, kemiri sunan (1st order) is the most preferred one to choose for biodiesel industry while monkey pod (10th order) is the least preferred one. According to Supriyadi *et al*. (2018), high oil yield is the criterion which makes kemiri sunan as one of the most potential biodiesel feedstock. Because of different priority vector the rest of the plants can be categorized as the following order lead (2nd), physic nut (3rd), indian beech (4th), nyamplung (5th), kapok (6th), indian milkweed (7th), cassia (8th), soursop (9th).

4.3.3 FFA Content (wt %)

Table 4.7 and Table 4.8 are the presentation of the pairwise comparison matrix and the result of AHP calculation regarding free fatty acid (FFA) content. Based on the result, indian milkweed (1st order) is the most feasible feedstock compared to other non-edible plants while monkey pod (10th) poses least value of priority vector indicating least preference. Phoo *et al*. (2014) considered indian milkweed as a potential biodiesel feedstock because of its higher free fatty acid (FFA) content. Having different priority vector, the other selected plants show different position in the order, such as nyamplung (2nd), cassia (3rd), physic nut (4th), kapok (5th), kemiri sunan (6th), lead (7th), soursop (8th), and indian beech (9th).

4.3.4 Oxidation Stability (h)

The pairwise comparison matrix of oxidation criteria is depicted as Table 4.9. In case of oxidation stability criterion, AHP analysis shows that nyamplung (1^{st}) is the ultimate choice as a feedstock for biodiesel production. Zakaria *et al*. (2014) mentioned about higher oxidation stability of nyamplung. On the contrary, lead (10^{th}) is considered as the least preferred choice as a feedstock following by the other feedstock which can be categorized in the following order: kemiri sunan (2^{nd}), physic nut (3^{rd}), monkey pod (4^{th}), indian beech (5^{th}), cassia (6^{th}), indian milkweed (7^{th}), kapok (8^{th}) and soursop (9^{th}) (Table 4.10).

4.3.5 Cold Filter Plugging Point (°C)

Result obtained from AHP computation by doing pairwise comparison matrix (Table 4.11) of this criterion shows that kapok (1^{st}) is the best choice as a biodiesel feedstock by following other feedstocks. According to Phoo *et al*. (2013), kapok is considered as an efficient biodiesel feedstock as it posses higher cold filter plugging point. Since kemiri sunan and soursop have same priority value (5^{th}order) it can be considered to have same preference and can be interchanged while choosing the feedstock for biodiesel production. According to the value of priority vector the non-edible feedstocks can be listed from highest to lowest order, such as indian beech (2^{nd}), physic nut (3^{rd}), nyamplung (4^{th}), monkey pod (6^{th}), cassia (7^{th}), indian milkweed (8^{th}), and lead (9^{th}) (Table 4.12).

4.3.6 Easiness to Grow in Marginal Land

According to the AHP result, lead is ultimate solution as a biodiesel feedstock having highest priority vector. The same priority vector is observed in case of nyamplung, kemiri sunan, indian beech and cassia which means the same preference as a biodiesel feedstock. Similar trend is followed by indian milkweed, kapok, soursop, and monkey pod. The pairwise comparison matrix and the result of AHP calculation are presented as Table 4.13 and Table 4.14 respectively.

4.3.7 Availability in Tropical Areas

Unlike other criterion, availability in tropical areas criterion shows that nyamplung and kemiri sunan are two most preferred choices as a biodiesel feedstock. Supriyadi *et al*. (2018) considered the criterion as an major advantage of using kemiri sunan as biodiesel feedstock. Monkey pod and lead have same preference having same priority value which is also observed in case of indian beech andkapok, soursop and cassia (Table 4.16). The pairwise comparison matrix of AHP calculation is shown in Table 4.15.

Table 4.3: Pairwise comparison matrix of alternatives for seed oil yield criterion

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1	2	2	2	3	4	4	9	9	9
2	0.5	1	1	1	2	3	3	5	5	5
3	0.5	1	1	1	2	3	3	5	5	5
4	0.5	1	1	1	1	2	2	4	4	4
5	0.33	0.5	0.5	1	1	2	2	3	3	4
6	0.25	0.33	0.33	0.5	0.5	1	1	2	2	2
7	0.25	0.33	0.33	0.5	0.5	1	1	2	2	2
8	0.11	0.2	0.2	0.25	0.33	0.5	0.5	1	1	1
9	0.11	0.2	0.2	0.25	0.33	0.5	0.5	1	1	1
10	0.11	0.2	0.2	0.25	0.25	0.5	0.5	1	1	1
1: Nyamplung, 2: Physic nut, 3: Kemiri sunan, 4: Indian beech, 5: Indian milkweed, 6: Kapok, 7: Soursop, 8: Cassia, 9: Monkey pod, 10: Lead.										

Table 4.4: Results obtained from AHP computations of seed oil yield criterion

Alternatives	Priority vector	Priority vector (%)	Priority rank	λmax, CI, RI	CR
Nyamplung	0.266743	26.7%	1	λmax = 10.05507 CI = 0.00612 RI =1.49	0.004126
Physic nut	0.154008	15.40%	2		
Kemiri sunan	0.154008	15.40%	2		
Indian beech	0.124057	12.40%	3		
Indian milkweed	0.098365	9.8%	4		
Kapok	0.056923	5.70%	5		
Soursop	0.056923	5.70%	5		
Cassia	0.029929	3.0%	6		
Monkey pod	0.029929	3.0%	6		
Lead	0.029114	2.90%	7		

Table 4.5: Pairwise comparison matrix of alternatives for oil yield criterion

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1	0.5	0.33	0.5	2	2	3	3	6	0.33
2	2	1	0.5	1	4	4	6	6	9	1
3	3	2	1	2	5	5	8	8	9	2
4	2	1	0.5	1	3	3	5	5	7	0.5
5	0.5	0.25	0.2	0.33	1	1	2	2	3	0.2
6	0.5	0.25	0.2	0.33	1	1	2	2	3	0.25
7	0.33	0.17	0.13	0.2	0.5	0.5	1	1	2	0.13
8	0.33	0.17	0.13	0.2	0.5	0.5	1	1	2	0.14
9	0.17	0.11	0.11	0.14	0.33	0.33	0.5	0.5	1	0.11
10	3	1	0.5	2	5	4	8	7	9	1

1: Nyamplung, 2: Physic nut, 3: Kemiri sunan, 4: Indian beech, 5: Indian milkweed, 6: Kapok, 7: Soursop, 8: Cassia, 9: Monkey pod, 10: Lead.

Table 4.6: Results obtained from AHP computations of oil yield criterion

Alternatives	Priority vector	Priority vector (%)	Priority rank	λmax, CI, RI	CR
Nyamplung	0.083133	8.3%	5	λmax = 10.12933 CI= 0.0144 RI= 1.49	0.009689
Physic nut	0.163399	16.3%	3		
Kemiri sunan	0.25329	25.3%	1		
Indian beech	0.135412	13.5%	4		
Indian milkweed	0.046869	4.7%	7		
Kapok	0.047845	4.8%	6		
Soursop	0.027217	2.7%	9		
Cassia	0.027565	2.8%	8		
Monkey pod	0.017573	1.8%	10		
Lead	0.197697	19.8%	2		

Table 4.7: Pairwise comparison matrix of alternatives for FFA content criterion

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1	2	3	7	0.5	2	6	2	9	4
2	0.5	1	2	4	0.5	1	4	1	6	3
3	0.33	0.5	1	2	0.25	0.5	2	0.5	5	1
4	0.14	0.25	0.5	1	0.13	0.25	1	0.25	2	0.5
5	2	2	4	8	1	2	8	2	9	6
6	0.5	1	2	4	0.5	1	3	1	7	3
7	0.17	0.25	0.5	1	0.13	0.33	1	0.25	2	1
8	0.5	1	2	4	0.5	1	4	1	7	3
9	0.11	0.17	0.2	0.5	0.11	0.14	0.5	0.14	1	0.5
10	0.25	0.33	1	2	0.17	0.33	1	0.33	2	1
1: Nyamplung, 2: Physic nut, 3: Kemiri sunan, 4: Indian beech, 5: Indian milkweed, 6: Kapok, 7: Soursop, 8: Cassia, 9: Monkey pod, 10: Lead.										

Table 4.8: Results obtained from AHP computations of FFA content criterion

Alternatives	Priority vector	Priority vector (%)	Priority rank	λmax, CI, RI	CR
Nyamplung	0.196796	19.70%	2		
Physic nut	0.119766	12.00%	4		
Kemiri sunan	0.063011	6.30%	6		
Indian beech	0.030116	3.00%	9		
Indian milkweed	0.253417	25.30%	1	λmax =10.121698 CI= 0.013 RI= 1.49	0.008725
Kapok	0.118284	11.80%	5		
Soursop	0.033751	3.40%	8		
Cassia	0.121619	12.20%	3		
Monkey pod	0.018751	1.90%	10		
Lead	0.04449	4.40%	7		

Table 4.9: Pairwise comparison matrix of alternatives for oxidation stability criterion

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1	2	2	5	9	9	9	6	2	9
2	0.5	1	0.5	2	7	7	7	3	1	7
3	0.5	2	1	3	9	9	9	5	2	9
4	0.2	0.5	0.33	1	3	3	3	2	0.5	3
5	0.11	0.14	0.11	0.33	1	1	1	0.5	0.2	1
6	0.11	0.14	0.11	0.33	1	1	1	0.5	0.17	1
7	0.11	0.14	0.11	0.33	1	1	1	0.5	0.14	1
8	0.17	0.33	0.2	0.5	2	2	2	1	0.33	3
9	0.5	1	0.5	2	5	6	7	3	1	7
10	0.11	0.14	0.11	0.33	1	1	1	0.33	0.14	1

1: Nyamplung, 2: Physic nut, 3: Kemiri sunan, 4: Indian beech, 5: Indian milkweed, 6: Kapok, 7: Soursop, 8: Cassia, 9: Monkey pod, 10: Lead.

Table 4.10: Results obtained from AHP computations of oxidation stability criterion

Alternatives	Priority vector	Priority vector (%)	Priority rank	λmax, CI, RI	CR
Nyamplung	0.27646	27.6%	1	λmax =10.108094 CI= 0.012 RI= 1.49	0.008098
Physic nut	0.147196	14.7%	3		
Kemiri sunan	0.221918	22.2%	2		
Indian beech	0.071724	7.2%	5		
Indian milkweed	0.024451	2.4%	7		
Kapok	0.023989	2.4%	8		
Soursop	0.02366	2.4%	9		
Cassia	0.047745	4.8%	6		
Monkey pod	0.139985	14.0%	4		
Lead	0.022873	2.3%	10		

Table 4.11: Pairwise comparison matrix of alternatives for CFPP criterion

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1	0.5	2	0.5	5	0.5	2	4	2	7
2	2	1	2	0.5	7	0.5	2	4	2	8
3	0.5	0.5	1	0.5	5	0.33	1	3	1	9
4	2	2	2	1	7	0.5	2	5	2	9
5	0.2	0.14	0.2	0.14	1	0.11	0.2	0.5	0.33	2
6	2	2	3	2	9	1	3	7	3	9
7	0.5	0.5	1	0.5	5	0.33	1	3	1	9
8	0.25	0.25	0.33	0.2	2	0.14	0.33	1	0.33	3
9	0.5	0.5	1	0.5	3	0.33	1	3	1	9
10	0.14	0.13	0.11	0.11	0.5	0.11	0.11	0.33	0.11	1
1: Nyamplung, 2: Physic nut, 3: Kemiri sunan, 4: Indian beech, 5: Indian milkweed, 6: Kapok, 7: Soursop, 8: Cassia, 9: Monkey pod, 10: Lead.										

Table 4.12: Results obtained from AHP computations of CFPP criterion

Alternatives	Priority vector	Priority vector (%)	Priority rank	λmax, CI, RI	CR
Nyamplung	0.121259	12.1%	4	λmax = 10.291701 CI= 0.0324 RI= 1.49	0.021854
Physic nut	0.145731	14.6%	3		
Kemiri sunan	0.086328	8.6%	5		
Indian beech	0.17286	17.3%	2		
Indian milkweed	0.02181	2.2%	8		
Kapok	0.236539	23.7%	1		
Soursop	0.086328	8.6%	5		
Cassia	0.032934	3.3%	7		
Monkey pod	0.08209	8.2%	6		
Lead	0.014122	1.4%	9		

Table 4.13: Pairwise comparison matrix of alternatives for easiness to grow in marginal land criterion

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1	0.33	1	1	3	3	3	1	3	0.33
2	3	1	3	3	7	7	7	3	7	1
3	1	0.33	1	1	3	3	3	1	3	0.33
4	1	0.33	1	1	3	3	3	1	3	0.33
5	0.33	0.14	0.33	0.33	1	1	1	0.33	1	0.11
6	0.33	0.14	0.33	0.33	1	1	1	0.33	1	0.11
7	0.33	0.14	0.33	0.33	1	1	1	0.33	1	0.11
8	1	0.33	1	1	3	3	3	1	3	0.33
9	0.33	0.14	0.33	0.33	1	1	1	0.33	1	0.11
10	3	1	3	3	9	9	9	3	9	1
1: Nyamplung, 2: Physic nut, 3: Kemiri sunan, 4: Indian beech, 5: Indian milkweed, 6: Kapok, 7: Soursop, 8: Cassia, 9: Monkey pod, 10: Lead.										

Table 4.14: Results obtained from AHP computations of easiness to grow in marginal land criterion

Alternatives	Priority vector	Priority vector (%)	Priority rank	λmax, CI, RI	CR
Nyamplung	0.090133	9.0%	3	λmax = 10.012673 CI= 0.0014 RI= 1.49	0.00094
Physic nut	0.245772	24.6%	2		
Kemiri sunan	0.090133	9.0%	3		
Indian beech	0.090133	9.0%	3		
Indian milkweed	0.030824	3.1%	4		
Kapok	0.030824	3.1%	4		
Soursop	0.030824	3.1%	4		
Cassia	0.090133	9.0%	3		
Monkey pod	0.030824	3.1%	4		
Lead	0.2704	27.0%	1		

Table 4.15: Pairwise comparison matrix of alternatives for plant availability in tropical areas criterion

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1	5	1	5	1	5	5	5	1	1
2	0.2	1	0.2	1	0.2	1	1	1	0.2	0.2
3	1	5	1	5	1	5	5	5	1	1
4	0.2	1	0.2	1	0.25	1	1	1	0.25	0.25
5	1	5	1	4	1	4	4	4	1	1
6	0.2	1	0.2	1	0.25	1	1	1	0.25	0.25
7	0.2	1	0.2	1	0.25	1	1	1	0.25	0.25
8	0.2	1	0.2	1	0.25	1	1	1	0.25	0.25
9	1	5	1	4	1	4	4	4	1	1
10	1	5	1	4	1	4	4	4	1	1
1: Nyamplung, 2: Physic nut, 3: Kemiri sunan, 4: Indian beech, 5: Indian milkweed, 6: Kapok, 7: Soursop, 8: Cassia, 9: Monkey pod, 10: Lead										

Table 4.16: Results obtained from AHP computations of plant availability in tropical areas criterion

Alternatives	Priority vector	Priority vector (%)	Priority rank	λmax, CI, RI	CR
Nyamplung	0.172449	17.2%	1	λmax = 10.017945 CI= 0.002 RI= 1.49	0.001344
Physic nut	0.03449	3.4%	4		
Kemiri sunan	0.172449	17.2%	1		
Indian beech	0.036852	3.7%	3		
Indian milkweed	0.157735	15.8%	2		
Kapok	0.036852	3.7%	3		
Soursop	0.036852	3.7%	3		
Cassia	0.036852	3.7%	3		
Monkey pod	0.157735	15.8%	2		
Lead	0.157735	15.8%	2		

4.4 Determination of Prior Biodiesel Feedstock

Determination of prior biodiesel producing plant was done based on Overall Priority Vector (OPV) of each criterion which is depicted in Table 4.17. The obtained result from priority determination shows that nyamplung (1st order) is the most efficient non-edible feedstock for biodiesel industry having highest Overall Priority Vector of 0.180. It was followed by kemiri sunan (2nd order) with OPV of 0.164, physic nut 0.150 (3rd order), indian beech 0.107(4th order), indian milkweed 0.095(5th order), lead 0.092 (6th order), kapok 0.076 (7th order), cassia 0.049 (8th order), soursop 0.043 (9th order) and monkey pod 0.043 (10th order). As soursop and monkey pod have same OPV, these plants are interchangeable while selecting preferred plant as a feedstock. Result of AHP analysis is presented in Figure 4.2.

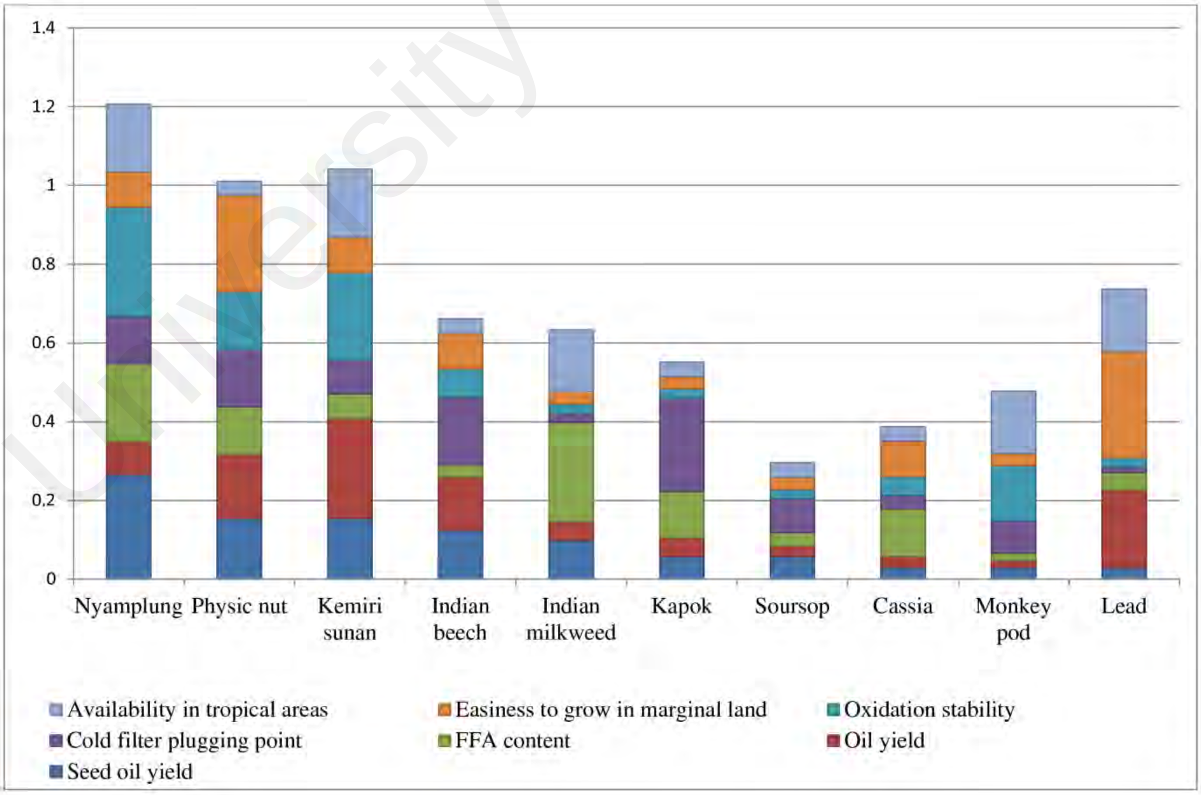


Figure 4.2: Alternatives choice values of biodiesel producing plants

Table 4.17: Result of priority determination calculation of alternatives

	Criteria							
Alternatives	Seed oil yield (0.3002)	Oil yield (0.2817)	FFA content (0.1664)	Cold filter plugging point (0.0899)	Oxidation stability (0.0865)	Easiness to grow in marginal land (0.0463)	Availability in tropical areas (0.0289)	Overall Priority Vector (OPV)
Nyamplung	0.26674	0.08313	0.19679	0.12126	0.27646	0.09013	0.17245	0.180
Physic nut	0.15401	0.16339	0.11977	0.14573	0.14719	0.24577	0.03449	0.150
Kemiri sunan	0.15401	0.25329	0.06301	0.08633	0.22192	0.09013	0.17245	0.164
Indian beech	0.12406	0.13541	0.03012	0.17286	0.07172	0.09013	0.03685	0.107
Indian milkweed	0.09837	0.04687	0.25342	0.02181	0.02445	0.03082	0.15774	0.095
Kapok	0.05692	0.04785	0.11829	0.23654	0.02399	0.03082	0.03685	0.076
Soursop	0.05692	0.02722	0.03375	0.08633	0.02366	0.03082	0.03685	0.043
Cassia	0.02993	0.02757	0.12162	0.03293	0.04775	0.09013	0.03685	0.049
Monkey pod	0.02993	0.01757	0.01875	0.08209	0.13999	0.03082	0.15774	0.043
Lead	0.02911	0.19769	0.04449	0.01412	0.02287	0.2704	0.15774	0.092

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Research Conclusion

The aim of this study is to suggest the most feasible non-edible plant oils for biodiesel production that can be an alternative to the current dependence on the edible oil resources worldwide. The selection procedure was conducted by using a priority estimation model known as Analytic Hierarchy process (AHP) which is helpful in decision making in complicated scenario. AHP analysis was done based on some criteria (seed oil yield, oil yield, free fatty acid (FFA) content, cold filter plugging point, oxidation stability, easiness to grow in marginal land and availability in tropical areas) of non-edible plant oil which were chosen by conducting Focus Group Discussion (FGD). During AHP analysis, the assessment on importance weight of criteria as well as non-edible plants was also done through Focus Group Discussion (FGD). According to the AHP analysis, the degree of influence of the selected criteria varied due to varied criteria weight. Seed oil yield was the criterion with highest influence while availability in tropical areas criterion had least influence. The obtained criteria weight from AHP calculation can be listed from the highest to the lowest value such as seed oil yield (0.3002), oil yield (0.2817), free fatty acid (FFA) content (0.1664), cold filter plugging point (0.0899), oxidation stability (0.0865), easiness to grow in marginal land (0.0463) and availability in tropical areas (0.0289).

Pairwise comparison matrix and AHP computation have been done to obtain the most potential plant as a biodiesel feedstock based on each criterion. The result shows that, nyamplung is the preferred choice in case of both seed oil yield and oxidation stability criteria. Considering oil yield criterion, kemiri sunan is the ultimate choice. When FFA content criterion is concerned, indian milkweed is the best choice and kapok is in cold filter plugging point criterion. Various choices are there while the other two criteria namely easiness to grow in marginal land and availability in tropical areas are considered.

The result of priority determination which was done by Overall Priority Vector (OPV) suggests that all the non-edible plants have the potential to be biodiesel feedstock whereas nyamplung is the most feasible one. The non-edible plants can be arranged in a numerical order based on weight obtained from AHP computation such as nyamplung (1^{st}), kemiri sunan (2^{nd}), physic nut (3^{rd}), indian beech (4^{th}), indian milkweed (5^{th}), lead (6^{th}), kapok (7^{th}), cassia (8^{th}), soursop (9^{th}) and monkey pod (10^{th}).

As AHP reduces bias decision by checking consistency, the result will be more reliable for future researchers. The results of the study could be useful to select non-edible plants to be developed in order to support the implementation of the government policy regarding biodiesel development. Moreover, findings from this study could aid decision making in the biodiesel industry to select best non-edible plant oil feedstock for biodiesel production.

Table 5.1: Summary of study findings

No.	Objectives	Findings
1	To establish the criteria influencing the selection of plant oil for biodiesel production	The criteria which can influence the biodiesel plant selection include seed oil yield, oil yield, free fatty acid (FFA) content, cold filter plugging point, oxidation stability, easiness to grow in marginal land and availability in tropical areas.
2	To analyze various plants oils for biodiesel production using Analytic Hierarchy Process (AHP).	Analytic Hierarchy Process (AHP) is used to analyze non-edible plant oils to prioritize one over another based on AHP analysis.
3	To suggest the most feasible plant oil for biodiesel production based on the AHP results	AHP analysis showed that nyamplung is the most feasible plant oil for biodiesel industry.

5.2 Future Research Recommendations

For future work, the following topics should be considered for making better decision in selecting the most potential feedstock for biodiesel production:

1) More non-edible plants which are already recognized as biodiesel feedstock should be added during AHP analysis. This can create a broad spectrum to choose the best feedstock for producing biodiesel.
2) More criteria should be considered during the evaluation of potential biodiesel feedstocks. As a result, the obtained result will be more reliable.
3) It is also recommended to include edible oil plants with non-edible oil plants for AHP analysis for a comparative study which can show a clear understanding of feedstocks to be explored widely.
4) Since importance weight of criteria as well as non-edible plants is determined by Focus Group Discussion (FGD), the experts involve in FGD plays an important role in the study. As this study involves five experts, it is recommended to involve more experts to make more accurate and reliable data for AHP calculations.

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LIST OF PUBLICATION AND PAPER PRESENTED

Published articles/publication:

Ilham, Z., & **Nimme, F. H.** (2019). Quantitative Priority estimation model for evaluation of various non-edible plant oils as potential biodiesel feedstock. *AIMS Agriculture and Food*, *4*(2), 303–319.

Presentation:

Nimme, F. H., & Ilham, Z. (2019). Potential of Non-edible Oil Feedstock for Biodiesel Production in South-East-Asian Region. *6th International Conference on Natural Science and Technology (ICNST' 19)*, 29th -30th March 2019. Asian University for Women, Chittagong, Bangladesh.