Evaluating Biodiesel Potential of Australian Native and Naturalised Plant Species

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Evaluating Biodiesel Potential of Australian Native and Naturalised Plant Species

By Associate Professor Nanjappa Ashwath

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Foreword

Australia’s economy relies heavily upon fossil fuels. We currently import about half of our liquid fuel - about $17 billion in value per year. Extensive use of fossil fuels is also contributing to global warming. Efforts are now being made to identify alternative and secure sources of fuel.

This report assesses the potential for using native plants as the feedstock for biodiesel production. Potential is assessed through screening a large number of species, short listing twenty species, and demonstrating the use of one of the native species for its biodiesel production potential, and testing the quality of the biodiesel thus produced via engine performance tests.

Biodiesel offers options for use on farm and locally to reduce purchases of conventional fuels as well as providing an alternative income source.

A feature of using native species as the biodiesel feedstock includes establishment of trees on lands that are presently not used for crop production, particularly on those lands that are considered marginal for food plant production. Growing biodiesel trees on these lands could attract carbon credits and the timber that remains after biodiesel production could serve as ‘superannuation’ to the growers, as they can realise cash from the sale of timber, after 10-20 years of establishing biodiesel feedstocks.

Australia has diverse flora, with some flora specially adapted to growing well on marginal lands as well as bearing large quantities of fruits and seeds that could serve as biodiesel feedstocks. However, the majority of species that have been identified as having biodiesel potential possess some limitations, such as difficulty in germination, establishment, harvesting, extraction of oil or conversion of oil into biodiesel. Further research is therefore required to address these issues so that the cost of production of biofuel can be reduced to make the biodiesel production process economical and competitive.

This project was funded from RIRDC Core Funds which are provided by the Australian Government. The study also benefited by a merit grant by CQUniversity Australia.

This report, an addition to RIRDC’s diverse range of over 2,000 research publications, forms part of our Bioenergy, Bioproducts and Energy program, which aims to meet Australia’s research and development needs for the development of sustainable and profitable bioenergy and bioproducts industries.

Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

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Managing Director
Rural Industries Research and Development Corporation
About the Author

Associate Professor Nanjappa Ashwath has been researching on Australian native plants over the past 27 years. He has selected tolerant species for salinity, waterlogging, acid soil and heavy metal tolerances. He has also contributed to conservation of native plants via establishing a native plant seedbank website (http://seedbank.cqu.edu.au) and developing tissue culture techniques for rare and threatened species. His research on phytoremediation of contaminated sites and phytocapping of landfills has culminated in developing novel techniques, and selecting highly useful plant species. He is a foundation member of the Centre for Plant and Water Science at Central Queensland University Australia, and currently supervises a number of researchers and post graduate students. He has also produced over 200 research publications and attracted research funds (>3 million) from various sources such as ARC, CRC, NHT, state and federal government and mining companies. His current research focuses on selecting native plants and algae for biodiesel production, and promoting the use of native species in Australia and overseas.

Acknowledgments

I am grateful to RIRDC (particularly to Dr Roslyn Prinsley) for their interest in native plants and supporting this project. Availability of seeds is the key requirement of this project, and most often it is not practical to collect seeds of a given species within a given time frame. Thus, we had to rely upon other sources. The generosity of various people in providing seeds, and/or allowing us to collect fruits from their land is very much appreciated—Barbara Taylor, Mark Murray and Paul Baker of Rockhampton Regional Council, and a dozen or so other native plant seed suppliers. The inclusion of a diverse range of species was only possible because of their co-operation. Processing seeds, extracting oil, analysing the oil for fatty acid profiles and conversion of the oil to biodiesel all needed concerted efforts of many, and I am grateful to our technical team, Roshan Subedi, Amanda Twomey, Dr Pramod Shrestha, Subhash Hathurusingha, Vineela Challagulla, Damian Byrt, Brock MacDonald, MarMar Thi and Graham Fox, for providing assistance with labour-intensive and often repetitive tasks. My sincere thanks also go to Professor David Midmore for his encouragement, and to Mrs Linda Ahern for the administrative support.

The information provided on the species is based on my own observations or studies, or that obtained from many of the references (see bibliography) and websites. Likewise, the distribution maps were sourced from the websites of the Australian Virtual Herbarium (http://www.ersa.edu.au/avh/; maps with blue background) and Weeds Australia (http://www.weeds.org.au/weedident.htm; maps without blue background). Photographs and the data relating to engine testing were provided by Mr Subhash Hathurusingha.

Two reviewers (Professor Kerry Walsh and Dr Naidu Bodapati) and the copy editors (Ms Lesley Walker and Ms Leonie Barnett) of Central Queensland University and RIRDC (Ms Catherine Poyner) helped improve the readability of the report. Their contributions are also acknowledged with thanks.
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<tbody>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
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<tr>
<td>AVH</td>
<td>Australia’s Virtual Herbarium</td>
</tr>
<tr>
<td>BL</td>
<td>Billion Litres</td>
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<tr>
<td>CE</td>
<td>Conversion Efficiency</td>
</tr>
<tr>
<td>CEC</td>
<td>Cation Exchange Capacity</td>
</tr>
<tr>
<td>CPWS</td>
<td>Centre for Plant and Water Science</td>
</tr>
<tr>
<td>CQ</td>
<td>Central Queensland</td>
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<tr>
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<td>Central Queensland University</td>
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<tr>
<td>CQUni</td>
<td>CQUniversity Australia</td>
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<tr>
<td>CRC</td>
<td>Co-operative Research Centre</td>
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<tr>
<td>DERM</td>
<td>Department of Environment and Resource Management</td>
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<tr>
<td>DTPA</td>
<td>Diethylene Triamine Pentaacetic Acid</td>
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<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
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<tr>
<td>FAME</td>
<td>Fatty Acid Methyl Ester</td>
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<tr>
<td>FAO</td>
<td>Food and Agricultural Organisation</td>
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<td>FAP</td>
<td>Fatty Acid Profile</td>
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<td>GHG</td>
<td>Greenhouse Gas</td>
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<tr>
<td>KOH</td>
<td>Potassium Hydroxide</td>
</tr>
<tr>
<td>MeOH</td>
<td>Methyl Alcohol</td>
</tr>
<tr>
<td>Mt</td>
<td>Million Tonnes</td>
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Executive Summary

What the report is about

This report evaluates the potential of using Australian native and naturalised plant species in biodiesel production. Particular emphasis is placed on species that occur in Central Queensland (CQ) region, as significant quantities of diesel are being imported to this region, and some proportion of this could be produced locally by establishing native species on cleared land that is readily available in CQ.

More than 200 species/provenances have been evaluated for oil content, of which 20 species have been selected as having commercial potential. One native species (*Calophyllum inophyllum*) has been fully tested from collecting seeds and extracting oil to testing engine performance of the biodiesel produced from this species.

Who is the report targeted at?

This report is intended for those who are involved in decision making on alternative fuels and global warming, landcare groups and mining companies; with the view to convincing them of the potential use of native and naturalised species in biodiesel production and sustainable regional development.

Background

Plants can be used successfully as biofuel feedstocks. For example, plant biomass can be used in gasification or ethanol production, starchy substance can be converted to ethanol, oils can be converted to biodiesel, and latex can also be processed to produce biofuels. In the current project, emphasis has been placed on testing plants that can produce oil seeds so that they may be used in biodiesel production.

The majority of landholders in CQ own/lease 1000–10,000 ha of land. Many also own diesel tractors or equipment that are old and need modification to accept low and ultra low sulphur diesel that is commercially available. Unfortunately many farmers cannot afford to convert their diesel engines. Furthermore, they will also find it difficult to purchase the mineral diesel, especially if the prices continue to escalate, as has been the case in the past five years. This may force at least some proportion of the farming community to abandon farming altogether. It is therefore critical that we plan in advance the ways by which the communities can be assisted in resolving their fuel crisis. The concept of using part of their land for biofuel production is being considered, as this would provide a sustainable solution while minimising the costs associated with fuel transport over long distances.

The target farming community will have adequate land area so that they can afford to set aside some portion of their land for growing biofuel plants. Establishment of these plants has the potential to improve ecological conditions and sustainability of the farm and provide a sustainable supply of biofuel for farm use. Growing biofuel feedstocks on farm and delivering it to centrally located processing plants (run as a co-operative) could also serve the interest of the rural community as a whole (Hobbs 2008). In addition, some of the tree biodiesel plants produce timber, and as such they could be used as ‘fixed deposit’ as farmers can harvest these trees (for timber) to generate income when needed.

The real issue is to find out which species of plants farmers can establish, how well they can produce biofuel, and what level of complications arise in implementing these measures. Amongst these issues, the major dilemma is what species to grow where, and how economical is this venture to generate fuel supply within the rural community. The current project mainly aims at identifying suitable species that have the ability to produce biodiesel, and the ones that could be established relatively easily on
farmlands of CQ. Further research is needed to determine specific details such as growth requirements, yield potential, harvesting procedures and mechanisation of oil extraction and biodiesel conversion.

**Aims/objectives**

The aim of this project was to assess biodiesel potential of native plants that occur in CQ, with the view to using these on marginal lands of CQ.

The objectives were to:

1. Identify potential native species that are capable of producing appreciable amounts of feedstock for biodiesel production, and are able to grow well on marginal lands of CQ.
2. Test the fruits/seeds/kernels of a large number of trees, shrubs, palm and ground cover species for oil content.
3. Examine oil yield potential of selected species in CQ.

**Methods used**

More than 200 plant species/provenances were selected based on their ability to produce abundant quantities of seeds and their natural occurrences in CQ. These species include trees, shrubs, palms, herbaceous species and some weedy species that grew easily in the region. Fruits or seeds were obtained from field collection, seedbanks and commercial seed companies. The seeds or kernels were separated and were analysed for oil content using n-hexane. Of those tested, 20 species were found to contain appreciable quantities of oil (>15%). The oils of selected species were analysed for fatty acid composition, and this data was used in calculating biodiesel properties. The oils of selected species were converted to biodiesel, and the basic properties of the biodiesels of 20 species were examined. Biodiesel of one species (*Calophyllum inophyllum*) was further tested for its fuel quality parameters and engine performance.

**Results/key findings**

Twenty of the 200 tested species/provenances showed a potential for use as biodiesel feedstocks. While these species contained appreciable amounts of oil (>15%), not all of them could be converted to biodiesel using the traditional base saturation method. Thus, a new method was developed to convert these oils into biodiesel. Conversion of the oils of some species was only possible with this modified method, indicating that development of this method was crucial to realise the biodiesel potential of some native species. The oils of selected species were also analysed for fatty acid composition, and the resulting data were used to calculate biodiesel quality. Biodiesel from one species, *Calophyllum inophyllum*, was subjected to complete fuel quality analysis, and was also tested for engine performance. These tests indicated that the biodiesel from this species meets ASTM standards. Since this species has great potential to grow in Central and Northern Queensland, economic viability of establishing this species needs to be established. It is estimated that this species can yield up to 3800 litres of biodiesel per hectare after 5-8 years of establishment.

**Where are the relevant industries located in Australia?**

The potential biofuel beneficiaries include either landholders or private industries. The former includes any rural landholders who have large areas of land on which biofuel plants may be grown and the feedstock supplied to a co-operative or to a factory which will have centralised seed processing, oil extraction and biodiesel conversion facilities. The model that Mr Steve Hobbs uses in Victoria, for rape seed should be appropriate for this purpose (Hobbs 2008).
The industry approach is where a single or multiple species of biofuel feed stocks are used to establish large plantations, and the feedstock can be processed locally as in the case of sugarcane industry (see Australian Phytofuels Pty Ltd).

Implications for relevant stakeholders

The study highlights the importance of native species as potential feedstocks for biodiesel production. The identified species will also help reverse land degradation problem while addressing fuel supply and global warming issues. This information should be brought to the attention of policy makers and acted upon by producer organisations, State and Federal funding agencies and private industries, particularly those involved with carbon sequestration.

Recommendations

Based on these studies, we conclude that up to 10 native species can be readily used as biodiesel feed stocks. These species can be grown either in monoculture or mixed cropping systems: *Calophyllum inophyllum*, *Aleurites moluccana*, *Pongamia pinnata*, *Cocos nucifera*, *Santalum acuminatum*, *Syagrus romanzoffiana*, *Santalum album*, *Ricinus communis*, *Atalaya hemiglauca*, *Argemone mexicana* and *Azadirachta indica* (Fig 1). They can also be used in agroforestry systems. Since many of these species were tested for the first time, further research is required to select the best provenances and to optimise agronomic practices, harvesting techniques, and seed processing and biodiesel conversion procedures.

Figure 1. A hypothetical situation wherein herbaceous (*Dianella caerulea*), shrub (*Cordyline manners-suttoniae/Petalostigma pubescens*), palm (*Syagrus romanzoffiana/Cocos nucifera*) and a tree species (*Calophyllum inophyllum/Pongamia pinnata*) can be used in a mixed crop planting.
Introduction

Australia has large reserves of solid fuel (e.g. coal) but only small quantities of liquid fuel resources (e.g. diesel). These resources are being exhausted at an alarming rate. The heavy use of imported fossil fuel by the motor, rail and mining industries subjects Australia to international oil price fluctuations. The use of petroleum fuel also contributes to greenhouse gas (GHG) emission.

Australia is one of the highest per capita emitters of greenhouse gases in the world. In 2002, Australia added about 550 million tons (Mt) of CO2 equivalent greenhouse gases. Most of this was due to consumption of petroleum fuel (51 billion litres) and coal (110 Mt). Given the future shortage and environmental concerns, the development of alternative sources of energy such as biodiesel and ethanol are essential. Biodiesel is usable without considerable modifications to diesel engines, while ethanol is usable in petrol engines only.

The current target for biofuel production is 350 ML by 2010 (O’Connell et al. 2007a). This target will be primarily achieved through manufacture of ethanol and biodiesel. While sugarcane and molasses are used as the primary sources of ethanol generation; waste oil, canola oil and tallow (animal fat) have been used as the major raw materials for biodiesel production. The use of food crops such as canola, corn, sorghum and wheat in biofuel production has been fraught with public dissatisfaction, as this use competes with food production. Furthermore, the net benefit of using such raw materials, particularly from the point of abating GHG emission is considered marginal if some of those crops are used as raw materials.

Another important problem faced by our nation is the increase in saline and degraded (mined) land; both of which are threatening the viability of our primary industries. About 5.7 Mha of productive land is currently salinised and this is estimated to increase to 17 Mha by 2050, unless corrective action is taken. Central Queensland (CQ) has vast areas of grazing (cleared) and degraded (mined) land on which biodiesel plants can be successfully established for complementing fuel supplies.

Although a number of native species have been assessed for growth on degraded land (Ashwath et al. 1994, Aswathappa and Marcar 1990, Aswathappa et al. 1986), very little is known regarding their biodiesel potential. Studies in India show that native species such as Pongamia can yield 3744 to 4399 litres of biodiesel/ha/yr (Azam et al. 2005, Nagendrappa 2000). These species and many other lesser-known native species that occur in Queensland can produce biodiesel at appreciable quantities. However, at present little is known about their biodiesel potential.

The production of canola, grains or sugarcane can occur on prime farmlands with fertile soils. Furthermore, some of these crops are often irrigated. However, vast areas of Australia do not have these luxuries and hence production of crops other than those listed above must be considered. Crops that yield non-edible products, such as pongamia, calophyllum, and moringa or mallee eucalypts are being considered for establishment in dry and marginal lands of Australia, but the progress has been very slow. Biomass gasification has also been trialled in Western Australia (Dr Colin Stucley; personal communication) using fast growing species of Eucalyptus (Whittington 2006).

This project addressed one of many ways of producing raw materials for biofuel production on dry and marginal lands of CQ. That is, to establish selected native and naturalised plant species that can yield biodiesel feedstocks. The majority of landholders in CQ own 1000–10,000 ha of land. They also own diesel tractors or equipment that are old and need to be modified to accept low and ultra low sulphur diesel. A large number of farmers cannot afford to convert their diesel engines to suit to new formulations of diesel, and they may also find it difficult to purchase the diesel if the price continues to escalate as has been observed over the past few years. This may force at least some proportion of the farming community to abandon farming altogether. It is therefore critical that we plan in advance the ways by which rural communities can be assisted in resolving their fuel crisis. The concept of using part of their land for biofuel production is being explored (and is currently practiced in southern
Australia using canola oil) as this would provide a sustainable solution while minimising the costs associated with the transport of fuel over long distances.

The target farming community will have sufficient land so that they can afford to set aside a portion for growing biofuel plants. Establishment of these plants has the potential to improve ecological conditions and the sustainability of the farm, as well as provide a continuous supply of biofuel for farm use. Growing biofuel feedstock on farm and delivering it to centrally located processing plants (run as a co-operative) could also further serve the health of the rural community as a whole (Hobbs 2008). In addition, some of the biodiesel producing trees can yield timber which could serve as ‘fixed deposits’ to farmers, so that they can harvest these trees to generate income when needed.

There is a need to find out which species of plants can be established as biodiesel feedstocks, test their production potential, develop harvesting and processing techniques, and finally convert the oil to biodiesel. Amongst these questions, the major dilemma is to find what species to grow where, and how economical this venture would be to provide fuel to the rural community. The current project is mainly aimed at identifying a suite of species that would have the ability to produce biodiesel and could be established relatively easily on farmlands of CQ.

Native plants can be selected for producing (i) biomass (for gasification or ethanol production from lignocellulose), (ii) oil seeds, (iii) leaf oil, (iv) starchy substances (grains or tubers) or (v) latex that can be processed to produce biofuels. In this project, emphasis has been placed on testing the plants that can produce large quantities of oil seeds so that they may be used in biodiesel production.

### Economic benefits

Australia consumes close to 19 billion litres of diesel fuel per annum, so even with a 5% blend, the planned biofuel production capacity will only meet about 50% of Australia's demand. Similar to ethanol in petrol, it can be expected that Australia will accept biodiesel as an alternative fuel for diesel and, like Europe and the US, will demand ever-increasing proportions of biodiesel added fuel. Several independent fuel groups are already adding 5% of biodiesel (B5) in the normal diesel and this level of addition is not required to be labelled.

Most of the planned developments have been based on a feedstock of tallow (animal fat) or imported vegetable oils. As the demand for the raw material increases due to an increase in demand for biodiesel, the value of the feedstock will also increase. Tallow in Australia is a finite resource with the production tied to slaughter numbers. Its cost has escalated over the last few years due to the usage in biodiesel production.

The Australian Renderers Association undertook a survey in 2000–2001 which indicated that total Australian tallow production was 517,000 tonnes, and total Australian domestic consumption was 177,000 tonnes, with 340,000 tons being exported (ca.60% of total production). Biodiesel from native plants could therefore serve as an alternative to tallow.

A serious worldwide shortage of biodiesel feedstock is expected, and the identification and promotion of Australian biodiesel plants can make a significant contribution to minimise this shortage.

Mining companies such as Anglo Coal are currently trialling biodiesel in heavy mining equipment (Brad Cartright; personal communication) and the rail industry has also conducted pilot studies on the use of biodiesel in rail engines (rail CRC). These stakeholders have great capacity to use biodiesel, thus providing long-term demand for this commodity.

### Environmental benefits

Central Queensland has vast areas of degraded land. Global and national trends towards biofuels, and the emphasis on establishing deep-rooted crops in CQ to minimise salinisation and to increase carbon
sequestration, fully support the idea of using degraded and grazing land for growing biodiesel crops. Establishment of biodiesel plants and production of biodiesel within the country could reduce the import of diesel from overseas and this could indirectly help preserve the rainforests in south-east Asia where these species are being bulldozed for oil palm production.

The use of biodiesel will also minimise global warming and air pollution compared to the use of imported fossil fuel.

**Social benefits**

The youth of farming communities in Australia prefer to move to cities than to live on farms, primarily due to marginal income generated from farming activities, and secondly due to uncertainties in making profits from these activities due to drought, cyclones and other natural disasters. Introduction of biodiesel plants to farming systems can provide additional income and this could help stabilise farm profits. As a result, the younger generation could opt to live on the farms rather than to migrate to cities.

An initiative in this program will minimise the land being used for producing food crops such as sorghum and canola for biofuel production. Establishment of biodiesel plants can result in reduced global warming, as they will fix carbon which will be recycled via biofuel production.

Appropriate use of biodiesel plants can also ensure long-term sustainability of farming systems due to reduced erosion and low rates of land degradation; to ensure better prospects for future generations.

**Adoption**

Initial stages of the study involved evaluation of selected species for oil content, and conversion of this into biodiesel to estimate biodiesel production potential of selected species. This required seed collection, oil extraction, biodiesel synthesis and testing of the qualities of the oil and the biodiesel. The information gathered from this project will provide the basis to considering native species as the potential feedstocks for biodiesel production. Further spreading of this information via various media will help promote the use of native plants and marginal lands for biofuel production in CQ.
Objectives

The aim of this project was to assess biodiesel potential of native plants that occur in Central Queensland, with the view to establishing these on marginal lands of Central Queensland. The objectives were to:

1. Identify potential native species that are capable of producing appreciable amounts of feedstock for biodiesel production, and are able to grow well on marginal lands of Central Queensland.

2. Test the fruits/seeds/kernels of a large number of trees, shrubs, palm and ground cover species for oil content.

3. Examine oil yield potential of selected species in Central Queensland.
Methodology

This study involved collection of seeds from the bushland in CQ, procurement of seeds from seed suppliers, processing of seeds following collection (e.g. drying, separation from fruit, cleaning), separation of kernels from seeds, the grinding of seeds/kernels, extraction of oil from ground seeds or kernels, characterisation of the resulting oil for various properties, and conversion of the oil into biodiesel.

The procedures involved in the above processes are briefly explained below.

Collection of fruits, seeds and other materials

Various sources were relied upon for the supply of test materials. These included the seeds stored in our seedbank (http://seedbank.equ.edu.au), seeds collected from around CQ, seeds procured from seed suppliers and seeds that were provided by local councils from their seedbanks. Seeds of more than 200 species/provenances were tested for oil content. A selected few species that contained appreciable quantities of oil (e.g. >15%) and produced large quantities of fruits were tested for biodiesel production. Leaves, husks and flowers of some species were also tested.

Seed collection and processing

The seeds used in the study were collected fresh, or were obtained from seed suppliers who had stored the seeds for varied periods under differing storage conditions. Those collected fresh were transported to the Centre for Plant and Water Science (CPWS) potting shed in woven plastic bags and were either air dried or oven dried at 30–40 °C for 3–5 days. The fruits were separated from the seeds, and fruits that did not dehisce were cracked open manually. The separated seeds or kernels were sieved, cleaned and stored at room temperature. Seeds of some species (e.g. *Syagrus, Calophyllum*) were non-dehiscent. Hence, they were either fermented to remove the husk or the entire fruit was dried. Once dried, the fruits were cracked open to collect the kernel.

The seeds that were procured from various sources were dried at 30–40 °C for 3–5 days, kernels separated where necessary, and seeds and kernels used in oil extraction. A separate sample was dried at 60 °C for 3–5 days to determine moisture content. Data from these samples were used to correct seed oil on dry weight basis.

Extraction of oil

Small quantities of seed/kernel materials were used in these trials (the majority were 10 g per replication). The analysis was done using 2-4 replications per species/provenance (the majority had 3 replications). After many trials of extracting oil from small quantities of seeds, the use of n-hexane was found to be the most expedient. Thus, the n-hexane double extraction method was adopted, as this has been used widely by various researchers as well as in commercial operations. Many commercial companies use the n-hexane method to extract oil (FAO 2010) and hence the method used here reflects the commercial situation. Initially, three extractions were carried out for each sample. As the recovery was marginal in the 3rd extraction, only two extractions were done for the majority of species.

The seeds or kernels were either ground using an industrial grade blender or were grated using a 1 mm grate (or sliced in a limited number of cases). The ground material was passed through a 1 mm sieve. Ten to 20 g of the prepared material was weighed into four 50 mL conical flasks. Three of these samples were used in oil extraction and the 4th sample was dried at 60 °C for 72 hours. The data from the 4th sample was used to express oil content on dry weight basis.
The weighed samples were treated with n-hexane at ca. 1:5 ratio (seed: hexane; w/v) and then placed on a rotary shaker (ca. 1000 rpm) in a fume hood for 10–15 hours. The seed extract was then decanted into a plastic container and fresh n-hexane (1:3) was added and shaken for a further 5–10 hours. The second extract was decanted into a separate plastic container and the sample was rinsed with fresh hexane and collected in the same container. The decanted hexane oil solution was allowed to evaporate in a fume hood for 1–2 days. The containers were weighed at regular intervals to determine the time required for n-hexane to completely evaporate from the oil solvent mixture. When constant weights were reached (5–10 hours), the oil weight was determined and the oil was transferred into glass bottles for further use. The seed oil content was calculated using the data of the first and second extract, and the oil content was expressed on dry weight basis using the data from the 4th sample that was used to determine dry weight.

For one species, viz *Calophyllum inophyllum*, the oil was extracted using an oil press (Fig. 2). The oil expression trials were carried out at Mr Steve Hobb’s workshop in Victoria. Based on this experience, a number of trials were conducted at CPWS using peanut as the feedstock. Finally, the settings of the oil press were optimised for *Calophyllum inophyllum* to extract bulk cold pressed oil for engine testings.

**Figure 2. Oil press used to obtain cold pressed oil from bulk seeds.**

**Characterisation of oil**

**Density and viscosity**

Oil density was measured at room temperature by dispensing one mL of the oil into a pre-weighed microfuge tube and then measuring the weight of the oil and the tube. An auto pipette with a disposable tip was used to dispense the oil, and three separate measurements were taken. Viscosity is the resistance of a fluid to flow through a tube. Oil viscosity was measured in accordance with ASTM Standard D445 using a Cannon-Fenske viscometer. The kinematic viscosity was determined at 40 °C by multiplying the viscometer tube constant with the measured efflux time. The efflux time is the time taken for a known volume of liquid measured at room temperature to pass through a calibrated glass capillary viscometer tube. All the measurements were replicated three times.
Acid value (number)

The acid value of extracted oil was determined by the acid base titration technique (ASTM D0664, Knothe et al., 2005). Initially, 10 mL of isopropyl alcohol was neutralised with 0.1% potassium hydroxide (KOH) to prevent the alcohol becoming acidic, as this would affect the results. Then, 1 mL of the oil was added to 10 mL pre-neutralised isopropyl alcohol, and the resulting solution was titrated against 0.1% KOH using phenolphthalein as the indicator. The quantity of KOH added up to the point when the reaction turned pink was measured, and the acid value (AN) was calculated.

\[ AN = \frac{(V_{eq} - b_{eq}) \times 56.1}{W_{oil}} \]

\( V_{eq} \) is the amount of titrant (mL) consumed by the oil sample and 10 mL of isopropanol solution at the equivalent point, \( b_{eq} \) is the amount of titrant (mL) consumed by 10 mL of isopropanol solution at the equivalent point, 56.1 is the molecular weight of KOH, N is the normality of 1% KOH (0.0178) and \( W_{oil} \) is the weight of oil.

Conversion of oil into biodiesel

Transesterification

In organic chemistry, transesterification is the process of exchanging the organic group \( R'' \) of an ester with the organic group \( R' \) of an alcohol. These reactions are often catalysed by the addition of an acid or base catalyst (Wikipedia 2010).

\[ R'OH + R''O'\rightarrow R''OH + R'O'\rightarrow \]

In other words, transesterification is the process of converting oil into biodiesel. In this process, fatty acids of the oil are converted into fatty acid methyl esters (FAME). This conversion is necessary, as the oils of different feedstocks will have differing flow properties (viscosity) and this could cause difficulties in fuel injection. Two methods were used to convert the oils into biodiesel as the most common method, the ‘base saturation method’ (Method 1), was not effective for converting a wide range of oils into biodiesel.

Method 1: Base catalysed transesterification protocol

In this method, 10 mL of the oil was transferred to a graduated tube and heated to 70 °C for 30 minutes to remove excess water. The solution was transferred to a glass beaker and allowed to cool to 55 °C. Then 2 mL of freshly prepared methoxide was slowly added while stirring the solution using a magnetic stirrer at 500 rpm (methoxide was prepared separately by adding 0.65g of KOH to 20 mL of 98% methanol until it became a clear solution). The oil and the methoxide were allowed to react for 2–3 hours at 65 °C. The solution was allowed to cool at room temperature and settle for 15 hours until a clear phase separation was observed. The top layer was measured as FAME, and the bottom layer was measured as the by-product. After phase separation, the volume of the top layer was determined and used to calculate conversion efficiency as:

\[ \text{CE} \% = \frac{\text{Vol of biodiesel}}{\text{volume of the oil used}} \times 100. \]
Method 2: Modified protocol for converting oil into biodiesel

In this protocol, toluene, methoxide, sulphuric acid and acetone were used according to Hathurusingha et al. (2009).

Fatty acid profiles of selected species

Species that had appreciable quantities of oil (>15%) in their seeds or kernels were selected, and the fatty acid composition of their oils was determined using a Hewlett Packard Plus 6890 series gas chromatograph (GC) equipped with a flame ionization detector (FID) and a capillary column of acidified polyethylene glycol (HP-INNOWax 19091N-133, 30 m × 250 μm × 0.25 μm).

The GC oven temperature ramp program was set at 150 °C for 1 min, heated at 2.9 °C/min up to 230 °C, where it was held for 1 min, with a total run time of 29 min. The esterified samples (1 μL) were injected to the GC and the methyl esters were identified by comparing the retention time of the sample to that of the external standard. Data of duplicate runs were used to calculate relative percentages of fatty acids. For GC analysis, methyl ester derivatives of the fats and oils were prepared according to Ichihara et al. (1996).
Engine performance test

The engine performance test was carried out by Mr Subhash Hathurusingha as part of his PhD studies and some of these results are shown here to demonstrate that the biodiesel from some of the native plants can be used as alternative sources of fuel. Seven litres of filtered cold pressed *Calophyllum* oil was converted into FAME using the 4-stage transesterification protocol (Method 2; Hathurusingha et al. 2009) and the resulting FAME was blended with 20 litres of high speed diesel (B20). The B20 blend was compared with high speed diesel. The vehicle tested was a 2.5 L Nissan caravan utility vehicle (Fig. 3). After making modifications to the fuel delivery system, the fuel was pumped through 2000 PRO 1 LT fuel consumption measuring equipment (Figures and data: Courtesy of Subhash Hathurusingha, PhD student, CQUniversity).

Figure 3. Arrangement of chassis dynamometer test (photos: Subhash Hathurusingha).

A MAHA LPS 2000 chassis dynamometer was used to measure (Fig. 4) engine power and fuel consumption. The experiment was carried out in three replicates. The chassis dynamometer had the following specifications (Table 1).
Table 1. Specifications of the MAHA LPS 2000 chassis dynamometer

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum speed</td>
<td>250 km/h</td>
</tr>
<tr>
<td>Maximum power</td>
<td>150 kW</td>
</tr>
<tr>
<td>Inertia tested</td>
<td>454–2752 kg</td>
</tr>
<tr>
<td>Room testing temperature</td>
<td>22–35 ºC</td>
</tr>
</tbody>
</table>

Figure 4. Display of engine performance data (photos: Subhash Hathurusingha).
Results and Discussion

Results of this study include:

- optimising methods of extracting seeds from the fruit, and oil from the seeds/kernel
- assessment of seed oil content of 200 species/provenances
- provenance variation in seed/kernel oil content
- estimated oil production from selected species
- properties of the oils derived from the potential 20 species
- methods of converting oil into biodiesel and the variations between species
- biodiesel properties of selected species/provenances
- engine performance of biodiesel from Calophyllum inophyllum
- descriptions of growth habit, seeds, seed oil, fatty acid composition, conversion and oil properties of selected species.

Optimising methods of extracting seeds from the fruits, and oil from the seeds/kernels

Separation of oil bearing material from the fruit was fraught with difficulties in species such as Syagrus romanzoffiana, Elaeocarpus grandis and Santalum species. These problems were overcome by cracking open the fruit and hand picking the kernels for experimental purposes. The seeds were also cracked using an electric mulcher. This method was only partly successful. For fruits with fleshy coverings, such as those of Calophyllum, Cordyline or Syagrus; fermenting the fruits for a known period helped remove the husk. Fruits of these species can also be dried, and the dried fruits can be cracked open to remove kernels. Fruits of Pongamia pinnata were cracked open by hand. However, mechanical methods similar to those used in the almond industry can be used to expedite the process. Fruits of many species were easy to handle as they would naturally split open on drying to release seeds which could then be sieved from the bulk of the material. This included acacias, castor, alectryon and jagera. Extraction of oil from Santalum species was found difficult due to stickiness. Wet grinding of Calophyllum kernels (with hexane) yielded lower levels of oil compared to dry grinding and sieving (<1 mm). In grinding the seeds/kernels, care should be taken to reduce the particle size to less than 1 mm, as particles any larger than this may prevent the n-hexane from reaching the oil located in the central part of the sample.

Since a diverse range of species were used in the study, and each species required different treatments for seed/kernel separation and oil extraction, a number of trials were undertaken to optimise oil extraction. Soft kernels such as Calophyllum were tested using grating, slicing, wet grinding and blending. Amongst these methods, the use of a commercial grade blender and passage of the ground material through a 1 mm sieve was found to be very effective and allowed extraction of the maximum oil percentage. Hence this method was used throughout the study. Pounding the seeds/kernels using a stone pestle and mortar and then sieving the ground material through 1 mm sieve was also found to be successful for species that had hard shells (e.g. Syagrus romanzoffiana).
Assessment of seed oil content of 200 species/provenances

This study assessed more than 200 species/provenances for oil content. The species used in the study are grouped into 5 classes, viz herbaceous species, palm-like species, palms, shrubs and trees.

The species that contain 1–10% oil are shown in pink coloured bars; those with 10–20% are shown in yellow coloured bars and the rest with >20% are represented by green coloured bars (Figs 5–11).

Seeds of herbaceous species such as *Dianella caerulea* and *Argemone mexicana* (Fig. 5) contained more than 15% of oil. While the former is a native species, the latter is a weed species that inhabits barren disturbed sites and abandoned crop lands. Presence of high levels of oil (up to 23%) in the seeds of *Argemone mexicana*, and its ease of cultivation, ease of separation of seeds from the capsules and the lower effort required to extract oil from the seed make this species a potential biodiesel crop, despite this being declared as one of the environmental weeds in Australia (Weeds Australia 2010). The other species, such as *senna*, *hibiscus*, *attriplex* and *lomandra*, that could produce fair quantities of seeds were found to contain low levels of oil and are not at all suitable for biodiesel production.

![Figure 5. Seed/kernel oil content of herbaceous species (the species with >20% oil are shown in green bars, the species with 10–20% oil are in yellow bars and those with <10% oil are represented in pink bars).](image-url)
The palm-like species (Fig. 6) included macrozamia, cordyline and xanthorrhoea. Amongst these, cordyline showed promising results (>15% oil) and also produces large quantities of seeds (see species description).

![Figure 6. Seed/kernel oil content of palm-like plants.](image)

A large range of palms were tested for oil content, with the hope of detecting some locally occurring palms that could contain equivalent of oil as in oil palm (Fig. 7). Amongst the 30 or so accessions tested, only two species, viz coconut palm and Queen palm contained appreciable amount of oils (>20%) in their kernels, and in Queen palm, marked variations were noted between the provenances (this aspect will be discussed later).

Up to 40 species and provenances of shrubs were tested for oil content (Fig. 8). Amongst these Mallotus philippensis, Murraya exotica, Murraya paniculata, Ochna serrulata, Petalostigma spp., Ricinus communis and Simmondsia chinensis contained >15% oil, and some up to 40% oil. Many of these species are easy to grow and they produce large amounts of seeds. The seeds can be readily harvested and separated from the fruits. Thus these species appear to have great potential for use as biodiesel feedstocks.
Figure 7. Seed/kernel oil content of palms.
Figure 8. Seed/kernel oil content of shrubs (the species with >20% oil are shown in green bars, the species with 10–20% oil are in yellow bars and those with <10% oil are represented in pink bars).

Trees were the major groups of plants tested for oil content (Figs 9, 10). These included 73 species and some of the provenances. The selected species differed markedly in their size, distribution, types of fruits produced, seed crop density, and the ease with which the fruits could be harvested and the seed oil extracted.
Amongst the tree species tested, some species contained high % oil (>30%), and these included *Elaeocarpus grandis*, *Aleurites moluccana* and *Calophyllum inophyllum*.

Those that had medium (20–30%) oil content consisted of *Pongamia pinnata*, *Santalum spicatum*, *Santalum acuminatum*, *Jagera pseudorhus*, *Brachychiton discolor*, *B. acerifolius*, *Atalaya hemiglauca*, *Alectryon conatus*, *Santalum album* and *Glochidion lobocarpum*.

Those having low oil (10–20%) included 16 species such as *Ficus microcarpa*, *Azadirachta indica*, *Sterculia quadrifida* and *Petalostigma pubescens*.

Species having very low oil content (10–15%) included >40 species/provenances such as acacias, cassias, bauhinias, araucaria, terminalia, peltophorum and harpulia.

A large number of species/provenances contained <10% oil and these were considered as not having any importance for biodiesel production, as their use solely for biodiesel production may not be economical.

The fact that a species contains high amount of oil also does not mean that that species is suitable for biodiesel production; for example, *Elaeocarpus grandis*. This species contains high % of oil in the kernels but the proportion of kernel compared to the whole fruit is very small. Furthermore, separation of the kernels from the fruits is extremely difficult, and most importantly, the kernel yield per tree is extremely low, thus grouping this species as having low potential despite the kernel containing a very high concentration of oil.

On the contrary, the species *Corymbia torrelliana* contained a low (8%) level of oil in the seeds, but the trees produce large quantities of seeds, and the seeds are very easy to harvest, separate and extract oil from. As a result, this species is considered a viable species for use in biodiesel production despite having low levels of oil in the seed.

There are many species that contain <10% oil. These species are regarded as having very little potential for biodiesel production despite their abundant production of fruits and ease of collection and extraction. In exceptional situations, those could potentially become a biodiesel feedstock. That is in the case where their cake can fetch a high price either as a high value protein source which indirectly compensates for the reduced revenue obtained from biodiesel production. In species such as *Podocarpus*, the cake may be used as an antioxidant, or in the case of *Melia azedarach*, the cake can be used as an insecticide; hence such species may be used in biodiesel production despite containing low concentrations of oil.
Figure 9. Seed/kernel oil content of tree species (the species with >20% oil are shown in green bars, the species with 10–20% oil are in yellow bars and those with <10% oil are represented in pink bars).
Figure 10. Fig 9 cont’d...Seed/kernel oil content of tree species
The foliage and seed husk or outer covering of the fruits can contain appreciable quantities of oil (e.g. eucalypts, olive). A few of the species were also tested for oil content in the foliage and the seed coats. Figure 11 shows that the extent of oil present in those parts is <3% which is lowest of all the sources tested so far. Although the diesel tree (*Copaifera longsdorfii*) contains higher quantities of non volatile oil, difficulties in extracting such low oil content may not be economical; despite this species producing large quantities of leaves. None of the limited number of species contained large quantities of oil in their shells or husks.

![Figure 11. Oil content of leaves and husks of selected species.](image)

**Provenance variations in seed/kernel oil content**

Provenances are the plants that belong to the same species but they occur at different locations ranging from a few 100 m to a few thousand km apart. These plants may or may not differ morphologically, but their physiological performance, yield characteristics, chemical composition or genetic constitution may differ from each other.

Examination of the oil content of different provenances of a species will provide an indication of the presence of genetic variability within the species. It also shows how that parameter is influenced by the environmental factors. The variations between provenances could therefore be contributed both by genetic and environmental factors.

Figures 12–13 show marked variations between provenances for seed/kernel oil content. A very high degree of variation is noticed for *Aleurites moluccana, Pongamia pinnata, Argemone mexicana, Petalostigma pubescens* and *Syagrus romanzoffiana*.

The species that showed the least provenance variation include *Euroschinus falcatus, Grevillea banksii, Jagera pseudorhus, Livistona spp., Petalostigma triloculare* and *Podocarpus elatus*.

Seed oil content is also influenced by the stage of maturity at which the fruits are harvested, storage conditions, the length of storage following collection and purity of the seed/kernel used in oil extraction.

In some species, such as *Petalostigma pubescens* it is extremely difficult to judge their maturity as they remain orange for a very long time (up to 2 months). The provenance difference shown here may therefore be attributed to differences in the maturity of the seeds on parent trees, as the seeds in these
experiments were obtained from various sources. These differences are difficult to avoid even if the same person collects seeds from different locations.

In the current project, seeds/kernels were procured from various sources. Thus part of the observed variations could be attributed to operator error. Even considering this aspect, a large number of species showed marked variation in seed oil content. This variation demonstrates the need to test more than one provenance of a species to be sure that the species is placed in the right category (low, medium, high category).

The variations observed in the data shown in Figures 12–13 can be attributed to operator associated, geographic or environmental variables as illustrated below:

<table>
<thead>
<tr>
<th>Factor</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole seed vs kernel</td>
<td>Elaeocarpus grandis, Moringa oleifera, Atalaya hemiglaucaken</td>
</tr>
<tr>
<td>Seasonal effect</td>
<td>Ricinus communis, Calophyllum inophyllum</td>
</tr>
<tr>
<td>Geographic factors</td>
<td>Dianella caerulea</td>
</tr>
<tr>
<td>Source</td>
<td>Aleurites moluccana, Jagera pseudo orus</td>
</tr>
<tr>
<td>Maturity</td>
<td>Argemone mexicana</td>
</tr>
<tr>
<td>Location</td>
<td>Syagrus romanzoffiana</td>
</tr>
</tbody>
</table>
Figure 12. Provenance variation in seed/kernel oil content of a wide range of plant species such as herbaceous species, palms, shrubs and trees (the species with >20% oil are shown in green bars, the species with 10–20% oil are in yellow bars and those with <10% oil are represented in pink bars).
Estimated oil production from 20 selected species

Twenty species were selected for further investigation. These species represented categories of low (10–20%), medium (20–30%) and high (>30%) oil content. Economic viability of a species depends very much upon oil content and several other parameters, such as the fruit yield, the ease of harvest, the ease of separation of seed/kernel from the fruit, the ability to store the fruits after harvest, the ease at which the oil can be extracted, conversion efficiency of the oil into biodiesel, and finally, the economic value of the cake produced from oil extract.

Table 2 shows the attributes of the selected 20 species for their seed/kernel oil content. Amongst all the species tested, Cocos nucifera, Aleurites moluccana, Calophyllum inophyllum, Syagrus romanzoffiana, Jagera pseudorhus and Oelma serrulata contained high (>30%) oil content. Santalum album, Murraya exotica, Pongamia pinnata, Petalostigma pubescens and Brachychiton acerifolius
contained medium (20–30%) oil content, whereas a large number of species contained low (10–20%) to very low (<10%) oil content.

The oil content of many native species has been determined for the first time and it is interesting to see how some of the poorly known species such as *Murraya exotica*, *Petalostigma pubescens*, *Dianella caerulea*, *Brachychiton bidwillii* and *Atalaya hemiglauca* contain a high level of oil and also produce reasonable quantities of fruit. These oils are currently evaluated for biodiesel properties. However, they may also have other benefits such as in medicine, automobile, paints, and other commercial applications. The by-products of oil extraction (cake, glycerine) could also provide valuable protein sources (e.g. *Sterculia quadrifida*), or they could serve as useful organic manure for crop production or pesticide synthesis.

Many weed species such as *Ochna*, castor and *Argemone* also contained considerable amounts of oils in their fruits/seeds. Their use in commercial production may be resisted by environmental groups. However, because they grow readily on these landscapes and can produce appreciable amounts of oil, these species should not be discounted for their use in biodiesel production.

The oils obtained from the 20 selected species were also assessed for acid value, density and viscosity. Amongst the 20 species, *Jagera pseudorhus*, *Brachychiton acerifolius*, *Brachychiton bidwillii*, *Argemone mexicana* and *Atalaya hemiglauca* had an acid value of >10, indicating that they may pose some constraints in converting to biodiesel via the standard base saturation method (Method 1). This was in fact the situation for *Brachychiton* spp. where the oils of these species could not be converted to biodiesel using Method 1 (no separation occurred). However, when Method 2 was used, 96–100%, conversion efficiency was achieved. The higher acid value seemed to have little effect on biodiesel conversion in *Argemone*, as 95% of the oil could be converted to biodiesel.

The oil property varied between species. The oils of ochna, brachychiton, castor, Queen palm, Chinese tallow and *Elaeocarpus* were solidified at room temperature (Fig. 14). The oil colour also differed from clear to amber (Fig. 14). The density of most oils was ca. 0.9. The oil from *Santalum album* and *Cordyline manners-suttoniae* had a low density of 0.79 and 0.85 respectively, whereas those of *Murraya exotica* and *Atalaya hemiglauca* had a density of just over 1.0.

Amongst all the oil parameters studied, viscosity of the oils of these species differed the most markedly. It ranged from 12–120, with the argemone, dianella, coconut, syagrus, jagera and ochna having a low viscosity, and *Santalum album* and castor oil seed having very high viscosity (90–120).

These species can be further grouped in three categories based on their ability to grow well in CQ, fruit yield, seed/kernel oil content, and the ease of extraction of seed from the fruit.

Group 1: includes the species that can readily be used in biofuel production. This consists of *Pongamia pinnata* (Karanja), *Calophyllum inophyllum* (beauty leaf tree), *Cocos nucifera* (coconut), *Syagrus romanzoffiana* (Queen palm), *Aleurites moluccana* (candle nut tree) and *Jagera pseudorhus* (jagera).

Group 2: the species that require further optimisation of growth conditions (agronomy) or seed processing. These include *Cordyline manners-suttoniae* (cordyline), *Petalostigma pubescens* (quarine bush), *Petalostigma triloculare*, *Dianella caerulea* (dianella), *Murraya exotica* (murraya), *Brachychiton bidwillii* (brachychiton), *Grevillea banksii* (grevillea) and *Santalum album* (sandalwood).

Group 3: the species that require wider acceptance and improvement in their agronomy, harvesting or seed processing. This category includes *Argemone mexicana* (Mexican poppy), *Ochna serrulata* (ochna), *Atalaya hemiglauca*, Chinese rain tree, *Brachychiton acerifolius* (flame tree) and *Ricinus communis* (castor).
Practical utilisation of these species in monoculture, mixed cropping or agroforestry needs to be judged carefully depending upon the site conditions. For example, one would consider establishing monoculture of a single species, or mixed cropping of several species. If mixed culture is considered, trees, shrubs and herbaceous species can be grown together to maximise biodiesel production. If the use of weedy species such as *argemone*, *ochna* or castor oil bush is considered, approvals should be sought from environmental departments.

![Variations in oil colour and solidifying properties of oils extracted from various species.](image)

**Figure 14.** Variations in oil colour and solidifying properties of oils extracted from various species.

**Methods of converting oil to biodiesel**

Two methods were used to convert oil to biodiesel. They were the most popular ‘base saturation method’ (Method 1) and the modified method (Method 2; Hathurusingha et al. 2009). The conversion potential of oils differed amongst the species and the methods used. Overall, Method 1 proved to be similar to Method 2, but the variability between species was much higher by Method 2. Another interesting feature of Method 2 was that this method proved to be beneficial to species that had high acid value and could not be converted to biodiesel using Method 1. For example, the oils of *Brachychiton* spp. could only be converted to biodiesel using Method 2. The efficiency of conversion in these species was high (96 to 103%).

The performance of Method 1 and Method 2 also varied between species. For example, Method 1 was superior to Method 2 for 3 species, on par with Method 2 for 4 species, produced low conversion for 2 species and was not effective for 2 species (Table 2). These trends clearly indicate that the method an operator chooses to convert oil to biodiesel must depend upon the plant species used in the conversion. Nevertheless, it should be noted that Method 2 was able to convert even recalcitrant oils such as those of *Brachychiton*, thus showing its superiority over Method 1 for some species.
Table 2. Seed/kernel oil content, acid value, density, viscosity and conversion efficiency of 20 selected species that have potential for use as biodiesel feedstocks. *The oil% values are averages of all provenances.

<table>
<thead>
<tr>
<th>Name of Species</th>
<th>Oil Content</th>
<th>Acid Value</th>
<th>Density</th>
<th>Viscosity</th>
<th>Conv-1</th>
<th>Conv-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cocos nucifera</td>
<td>50.81 ± 1.1</td>
<td>0.53 ± 0.4</td>
<td>0.91</td>
<td>14.55 ± 0.12</td>
<td>103 ± 1.2</td>
<td>110 ± 3.0</td>
</tr>
<tr>
<td>Aleurites moluccana</td>
<td>46.73 ± 8.23</td>
<td>0.63 ± 0.06</td>
<td>0.93</td>
<td>24.63 ± 0.12</td>
<td>97 ± 2.3</td>
<td>107 ± 1.5</td>
</tr>
<tr>
<td>Calophyllum inophyllum</td>
<td>46.51 ± 4.49</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Syagrus romanzoffiana</td>
<td>41.64 ± 3.78</td>
<td>3.49 ± 0.06</td>
<td>0.94</td>
<td>15.50 ± 0.06</td>
<td>105 ± 0.3</td>
<td>111 ± 3.5</td>
</tr>
<tr>
<td>Jagera pseudorhus</td>
<td>34.01 ± 0.62</td>
<td>5.11 ± 0.06</td>
<td>0.92</td>
<td>15.47 ± 0.03</td>
<td>90 ± 1.5</td>
<td>94 ± 2.1</td>
</tr>
<tr>
<td>Ochra serrulata</td>
<td>31.16 ± 0.00</td>
<td>6.81 ± 0.03</td>
<td>0.87</td>
<td>15.53 ± 0.03</td>
<td>97 ± 8.3</td>
<td>86 ± 4.1</td>
</tr>
<tr>
<td>Santalum album</td>
<td>24.49 ± 3.23</td>
<td>6.42 ± 0.09</td>
<td>0.79</td>
<td>120.17 ± 0.1</td>
<td>95 ± 2.1</td>
<td>101 ± 2.0</td>
</tr>
<tr>
<td>Chinese rain tree</td>
<td>22.17 ± 0.51</td>
<td>1.57 ± 0.03</td>
<td>0.92</td>
<td>23.23 ± 0.3</td>
<td>111 ± 0.9</td>
<td>—</td>
</tr>
<tr>
<td>Pongamia pinnata</td>
<td>21.86 ± 0.36</td>
<td>2.14 ± 0.05</td>
<td>1.11</td>
<td>19.47 ± 0.03</td>
<td>96 ± 1.9</td>
<td>—</td>
</tr>
<tr>
<td>Petalostigma pubescens</td>
<td>21.13 ± 2.37</td>
<td>9.78 ± 0.06</td>
<td>0.94</td>
<td>29.80 ± 0.12</td>
<td>97 ± 0.3</td>
<td>102 ± 2</td>
</tr>
<tr>
<td>Brachychiton acerifolius</td>
<td>19.86 ± 2.17</td>
<td>8.18 ± 0.06</td>
<td>0.89</td>
<td>22.33 ± 0.09</td>
<td>ns</td>
<td>96 ± 7.9</td>
</tr>
<tr>
<td>Ricinus communis</td>
<td>19.55 ± 1.03</td>
<td>5.82 ± 0.03</td>
<td>0.99</td>
<td>95.93 ± 0.07</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Petalostigma triloculare</td>
<td>19.06 ± 0.07</td>
<td>1.98 ± 0.02</td>
<td>0.94</td>
<td>24.57 ± 0.42</td>
<td>98 ± 2.5</td>
<td>103 ± 2.0</td>
</tr>
<tr>
<td>Dianella caerulea</td>
<td>18.66 ± 2.6</td>
<td>3.74 ± 0.08</td>
<td>0.89</td>
<td>14.37 ± 0.03</td>
<td>100 ± 0.1</td>
<td>—</td>
</tr>
<tr>
<td>Argemone mexicana</td>
<td>18.38 ± 5.4</td>
<td>—</td>
<td>0.89</td>
<td>12 ± 0.06</td>
<td>97 ± 0.5</td>
<td>95 ± 4.5</td>
</tr>
<tr>
<td>Cordyline manners-s</td>
<td>15.84 ± 1.77</td>
<td>15.41 ± 0.07</td>
<td>0.85</td>
<td>20.43 ± 0.03</td>
<td>101</td>
<td>98 ± 1.2</td>
</tr>
<tr>
<td>Atalaya hemiglauca</td>
<td>15.62 ± 5.53</td>
<td>13.86 ± 0.43</td>
<td>1.02</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Grevillea banksii</td>
<td>13.85 ± 1.21</td>
<td>13.82 ± 0.03</td>
<td>0.93</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Brachychiton bidwillii</td>
<td>11.15 ± 3.37</td>
<td>25.80 ± 0.14</td>
<td>0.90</td>
<td>23.03 ± 0.09</td>
<td>ns</td>
<td>103 ± 1.4</td>
</tr>
</tbody>
</table>

Fatty acid composition of the oils derived from various species

The oils of the selected 20 species were analysed for 25 fatty acids using GC. The fatty acid compositions of the oils of these species are detailed under individual species descriptions, and only the overall trends are discussed here.

As expected, fatty acid compositions of the selected species contained high percentages of oleic and linoleic acids (Tables 3, 4). While some of these fatty acids are saturated, the others are unsaturated. For favourable conversion into biodiesel, the proportion of saturated and unsaturated fatty acid composition should be present at an optimum ratio. High proportions of linoleic acid (>10%) prove that the oil is unstable for biodiesel conversion. Aleurites moluccana contains 29.1% of linolenic acid and this suggests that the biodiesel from this species may not be suitable for use in motor vehicles.
The species that contained the highest proportion (>40%) of various fatty acids (in descending order) are shown in Table 4.

**Table 3. Fatty acid compositions of the standard used in the gas chromatograph.** Note that fatty acids 1–14 were identified and quantified based on the internal standard used, whereas fatty acids 15–26 were diagnosed based on the retention time.

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Formula</th>
<th>Systemic name</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Octanoic acid</td>
<td>C₈H₁₆O₂</td>
<td>Caprylic</td>
<td>8:0</td>
</tr>
<tr>
<td>2. Decanoic acid</td>
<td>C₁₀H₂₀O₂</td>
<td>Capric</td>
<td>10:0</td>
</tr>
<tr>
<td>3. Lauric acid</td>
<td>C₁₂H₂₄O₂</td>
<td>Dodecanoic</td>
<td>12:0</td>
</tr>
<tr>
<td>4. Myristic acid</td>
<td>C₁₄H₂₈O₂</td>
<td>Tetradecanoic</td>
<td>14:0</td>
</tr>
<tr>
<td>5. Palmitic acid</td>
<td>C₁₆H₃₂O₂</td>
<td>Hexadecanoic</td>
<td>16:0</td>
</tr>
<tr>
<td>6. Palmitoleic acid</td>
<td>C₁₆H₃₀O₂</td>
<td>(Z)-9-hexadecenoic</td>
<td>16:1</td>
</tr>
<tr>
<td>7. Stearic acid</td>
<td>C₁₈H₃₆O₂</td>
<td>Octadecanoic</td>
<td>18:0</td>
</tr>
<tr>
<td>8. Oleic acid</td>
<td>C₁₈H₃₄O₂</td>
<td>cis-9-Octadecanoic</td>
<td>18:1 (n9c)</td>
</tr>
<tr>
<td>9. Linoleic acid</td>
<td>C₁₈H₃₂O₂</td>
<td>cis-9, cis-12-Octadecenedioic</td>
<td>18:2</td>
</tr>
<tr>
<td>10. Linolenic acid</td>
<td>C₁₈H₃₀O₂</td>
<td>cis-6, cis-9, cis-12-Octadecenedioic</td>
<td>18:3</td>
</tr>
<tr>
<td>11. Arachidic acid</td>
<td>C₂₀H₄₀O₂</td>
<td>Eicpsanpoic</td>
<td>20:0</td>
</tr>
<tr>
<td>12. Behenic acid</td>
<td>C₂₂H₄₄O₂</td>
<td>Docosanoic acid</td>
<td>22:0</td>
</tr>
<tr>
<td>13. Erucic acid</td>
<td>C₂₂H₄₂O₂</td>
<td>(Z)-Docos-13-enioic acid</td>
<td>22:1</td>
</tr>
<tr>
<td>14. Lignoceric acid</td>
<td>C₂₄H₄₈O₂</td>
<td>Tetracosanoic acid</td>
<td>24:0</td>
</tr>
<tr>
<td>15. Undecylic acid (2:38 min)</td>
<td>C₁₁H₂₂O₂</td>
<td>Undecanoic acid</td>
<td>11:0</td>
</tr>
<tr>
<td>16. Tridecanoic acid (4:25 min)</td>
<td>C₁₃H₂₄O₂</td>
<td>—</td>
<td>13:0</td>
</tr>
<tr>
<td>17. Margaric acid (8.87 min)</td>
<td>C₁₃H₂₄O₂</td>
<td>Heptadecanoic acid</td>
<td>17:0</td>
</tr>
<tr>
<td>18. Elaidic acid (13:08-13:32 min)</td>
<td>C₁₈H₃₄O₂</td>
<td>(E)-octadec-9-enioic acid</td>
<td>18:1 (n9t)</td>
</tr>
<tr>
<td>22. Linoleaidic acid (14:60 min)</td>
<td>C₁₈H₃₂O₂</td>
<td>trans, trans-9,12-octadecadienoic acid</td>
<td>18:3</td>
</tr>
<tr>
<td>23. 16:15 min (?)</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>24. Eicosenoic acid (17:76 min)</td>
<td>C₂₀H₃₈O₂</td>
<td>(Z)-Eicos-11-enioic acid</td>
<td>20:1</td>
</tr>
<tr>
<td>25. Eicosadienoic acid (18:16 min)</td>
<td>C₂₀H₃₈O₂</td>
<td>11,14-eicosadienoic acid</td>
<td>20:2</td>
</tr>
<tr>
<td>25. Arachidonic acid (20:76 min)</td>
<td>C₂₀H₃₂O₂</td>
<td>all-cis-5,8,11,14-eicosatetraenoic acid</td>
<td>20:4</td>
</tr>
<tr>
<td>26. Docosadienoic acid (23:01 min)</td>
<td>C₂₂H₄₀O₂</td>
<td>cis-13,16-docosadienoic acid</td>
<td>22:2</td>
</tr>
</tbody>
</table>
Table 4. Fatty acid compositions (%) of various species in descending order.

<table>
<thead>
<tr>
<th>Ochna serrulata (50)</th>
<th>Brachychiton acerifolius (16)</th>
<th>Santalum spicatum (54.6)</th>
<th>Dianella caerulea (65.4)</th>
<th>Aleurites moluccana (29.1)</th>
<th>Cocos nucifera (46.76)</th>
<th>Syagrus romanzoffiana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elaeocarpus grandis (24)</td>
<td>Calophyllum inophyllum (15)</td>
<td>Santalum acuminatum (54.4)</td>
<td>Cordyline manner-s (55.3)</td>
<td>Murraya exotica (4.6)</td>
<td>Koelreuteria formosana (4.3)</td>
<td>Petalostigma pubescens (0.57)</td>
</tr>
<tr>
<td>Brachychiton sp. (AT (23))</td>
<td>Brachychiton sp.</td>
<td>Pongamia pinnata (53.2)</td>
<td>Argemone mexicana (53.5)</td>
<td>Koelreuteria formosana (4.3)</td>
<td>Petalostigma triloculare (0.6)</td>
<td></td>
</tr>
<tr>
<td>Brachychiton acerifolius (21)</td>
<td>Ricinus communis (10.9)</td>
<td>Petalostigma pubescens (52.6)</td>
<td>Leucaena leucocephala (45.7)</td>
<td>Aleurites moluccana (36.7)</td>
<td>Santalum acuminatum (2.5)</td>
<td></td>
</tr>
<tr>
<td>Brachychiton bidwilii (20)</td>
<td>Grevillea banksii (49.2)</td>
<td>Elaeocarpus grandis (47.6)</td>
<td>Calophyllum inophyllum (35.1)</td>
<td>Pongamia pinnata (2.4)</td>
<td>Santalum spicatum (2.1)</td>
<td></td>
</tr>
<tr>
<td>Bauhinia purpurea (19)</td>
<td>Grevillea banksii</td>
<td>Elaeocarpus grandis (47.6)</td>
<td>Atalaya hemiglauca (46.4)</td>
<td>Atalaya hemiglauca (2.1)</td>
<td>Bauhinia purpurea (2.1)</td>
<td></td>
</tr>
<tr>
<td>Leucaena leucocephala (18)</td>
<td>Brachychiton sp.</td>
<td>Pongamia pinnata (7.9)</td>
<td>AT (0.8)</td>
<td>Petalostigma (2.5)</td>
<td>Petalostigma (0.25)</td>
<td></td>
</tr>
<tr>
<td>Ricinus communis (16)</td>
<td>Elaeocarpus grandis (7.9)</td>
<td>Brachychiton acerifolius (40.5)</td>
<td>Calophyllum inophyllum (36.4)</td>
<td>Brachychiton acerifolius (26)</td>
<td>Santalum spicatum (0.22)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Cordyline manners-s (15)</td>
<td>Pongamia pinnata (7.9)</td>
<td>Syagrus romanzoffiana (33.8)</td>
<td>Petalostigma pubescens (23.4)</td>
<td>Pongamia pinnata (0.20)</td>
<td></td>
</tr>
</tbody>
</table>
Biodiesel properties of selected 20 species

The oils derived from selected species were characterised for various biodiesel properties such as saponification number (SN), which represents the number of milligrams of potassium hydroxide or sodium hydroxide required to saponify 1 g of fat under specified conditions, cetane number (CN), which is used to test ignition delay time, and combustion quality. Higher cetane numbers give better ignition properties (Meher et al. 2006). An adequate CN is required for good engine performance. High CN helps ensure good cold start properties and minimizes formation of smoke.

Iodine value is a measure of total unsaturation within a mixture of fatty acid. It is expressed in grams of iodine that react with 100 g of the respective sample when formally adding iodine to the double bonds (Knothe et al. 2005). Unsaturated fatty acids are important as they help maintain the oil in liquid form (Ramos et al., 2009).

Oils of all selected 20 species were analysed for fatty acid compositions (see for example Figs 15–18), based on the use of an external standard (Fig. 15) and published references (David et al. 2003 and Vickers 2007).

The oils of these species were also converted to biodiesel. Only the biodiesel derived for *Calophyllum inophyllum* has been assessed for biodiesel quality and engine performance as part of the PhD program of Mr. Subhash Hathurusingha. These results are presented under *C. inophyllum* on page 38 onwards.

![Figure 15. GC/FID Chromatogram of the methyl esters of the external standard.](image-url)
Figure 16. GC/FID Chromatogram of the methyl esters of *Calophyllum inophyllum*.

Figure 17. GC/FID chromatogram of *Jagera pseudorhus*.

Figure 18. GC/FID chromatogram of *Koelreuteria formosana*.
Photographs of other Australian plants showing abundant fruit bearing capacity, but having little biodiesel potential

The following species (Fig. 19) produce large quantities of fruits but they contain very low % of oil, so they were considered unsuitable for biodiesel production.

Figure 19. Carpentaria palm, royal palm, date palm, cassia and leucaena that grow well in Central Queensland, but have little biodiesel potential due to low oil content.
Potential species for biodiesel production: their habitat description, oil content, fatty acid profiles and biodiesel conversion

1 **Calophyllum inophyllum** (Beauty leaf tree)

The Beauty leaf tree is a perennial plant that usually occurs in the coastal areas of Queensland and the Northern Territory. It is also widespread in South East Asia, India and Sri Lanka. Some trees of more than 200 years age occur in northern Queensland and have attained a trunk diameter of ca. 200 cm. The Beauty leaf tree is traditionally used as a source of medicine (Domba oil) and as a timber (Hathurusingha et al. 2009). This tree flowers twice a year and produces up to 8000 fruits per plant in a year. The fruits contain a kernel each of which weighs about 5 grams (dry wt) and contain non-edible oil of 46% (Table 5).

While the majority of plants occur naturally in the coastal areas of Australia, amenity plantings along roadsides (Darwin) and in parks (Cairns, Townsville and Bowen) have also occurred. In Australia, the Beauty leaf tree tends to occur in free draining soils along the coastal region, but in Sri Lanka it grows well in clay soils along the bunds of paddy fields (Hathurusingha; personal communication). This shows that the Beauty leaf tree has the potential to grow in a wide range of soils. Extensive studies have been undertaken on its natural variation (Hathurusingha; PhD thesis in preparation) for its growth and fruit qualities, including oil content and fatty acid profiles. The presence of wide variability suggests that suitable genotypes can be selected to any specific location and soil type.

Although no agronomic studies have yet been conducted, based on observed growth in its natural range and in the planted areas, this tree can be established as a biodiesel feedstock crop either in monoculture or in mixed planting with other biodiesel feedstocks or food crops (agroforestry).

The oil is of golden colour, typical of a vegetable oil - if extracted from fresh seeds using n-hexane. However, the use of stored seeds in cold press results in a dark sooty colour. The colour change occurs probably due to the presence of resins in the kernels which undergo chemical changes following harvest (Fig. 14).

The oil content of the kernel is 46% (Table 5). The oil has a species-specific odour and can be readily converted into biodiesel using a modified method (Hathurusingha et al. 2009). Conversion rates of up to 88% can be achieved with the modified method. The cake (54%) resulting from oil extraction could serve as valuable organic material and also be useful in compost tea preparation. There is also the potential to use the cake as a soil insecticide to control soil nematodes.

Huge variations occur amongst provenances for plant growth parameters, oil content, fatty acid profiles and biodiesel conversion properties (Hathurusingha; PhD thesis in preparation). Tests have also been conducted to assess fuel efficiency (B20), engine performance and emission features using the biodiesel from the Beauty leaf tree (Hathurusingha et al. 2009). These tests clearly show that the biodiesel from this species is as energy efficient as mineral diesel, with an additional benefit of having a cleaner emission.
Cultivation: Beauty leaf tree grows well in open sun; hence this can be grown as an upper storey species. It can also be established as a mid-storey crop, if grown with coconut or Queen Palm. However, the seedlings of Australian origin appear to be sensitive to open sun and they may be required to be grown under partial shade during early nursery production.

Provenance variations in Beauty leaf tree: morphological and oil properties

Three study sites, viz Cardwell, Townsville and Yeppoon were selected in Queensland (Fig. 20), and the sites were inspected on two occasions; one in April 2008 (as part of the CQUniversity sponsored merit grant) and the other in June 2008. During the first trip, plant and soil samples were collected and measurements such as tree height, diameter at breast height (DBH), canopy diameter and soil depth were made and samples of leaves and soil were brought to the laboratory for chemical analysis. During the second field trip in June 2008, fruits were collected from the previously sampled trees.

The fruit were brought to CPWS potting shed and assessed for fruit volume, fruit length and breadth, skin thickness, shell thickness, kernel width, kernel length, kernel weight, kernel to husk weight ratio, kernel moisture content and kernel oil content. Up to 30 randomly selected seeds from each site were assessed for the above parameters and the kernels derived from the above analysis were used in determining kernel oil content. After trialling various techniques of extracting oil, we found that the use of n-hexane to extract oil from grated kernels was highly effective. This procedure was used throughout the study. The seed oil thus obtained was used in synthesising biodiesel via a 4-stage transesterification process. Both the oil and the biodiesel obtained from this procedure are being further tested for fatty acid composition and other essential qualities of biodiesel, respectively, using a GC.

Figure 20. *Calophyllum inophyllum* distribution and provenances. 

Variations in seed germination

The seeds that were collected from the above sites were germinated in the greenhouse to determine germination percentage and to record variations in seedling morphology.

Fruits or kernels from different provenances were germinated in pots containing washed river sand (Fig. 21). Five or ten seeds were used per pot (depending on the availability of seeds for each provenance), and up to five replications per provenance were used. The number of seeds germinated at different times was counted to determine seed germination percentage. The height of seedlings and the number of leaves produced by each of the germinated seeds were also recorded over 12 months and these seedlings will be further assessed for morphological variations such as leaf hairiness, stomatal
density, venation and other characteristics that will help delineate differences between the
provenances.

![Image](image.png)

**Figure 21.** The set up used to study variations in seed germination and seedling morphology
and growth.

**Variations in seed oil content and quality**

Ripened seeds from various sites were collected. Each sample was separately soaked for 6 hours,
excess water was drained, and husks were removed and desiccated for 14 days at \(<35^\circ\)C. Oil was
extracted via standard n-hexane extraction. The oil content of each provenance was assessed against
soil and climatic parameters with the view to identifying the conditions that produce the highest seed
oil content and oil yield per hectare of land.

Oils of six different provenances were extracted using standard n-hexane extraction and were tested
for fatty acid profile (FAP) using GC. Significant variations in FAP were observed among various
provenances. By using the results of the FAP analysis and empirical formulas (Kalyasiri et al. 1996), a
number of biodiesel parameters were determined. These parameters were then correlated with each
fatty acid to determine its effect on biodiesel quality.

**Variations in growth forms**

Tree size varied significantly between the sites, both due to the age of the tree and to the soil and other
climatic conditions. The trees found at Cardwell were the largest (Fig. 22) with the trunk diameter
range of 2–3 metres. There were also younger trees in the parklands as well as natural sites at
Cardwell. In contrast, the trees found at Townsville (Fig. 22) were all planted by the Council, and
were probably 10 years old. The trees growing near Yeppoon were of similar size as those in
Townsville, but the form was different. Only one tree was found at Bell Park in Emu Park and this is a
large tree with stem girth of 80 cm. This tree showed large variation in fruit size, with some the
smallest and others largest of all the fruits collected at different locations. The majority of smaller
fruits from this site contained no kernel.

**Growth habitats**

*Calophyllum* occurs on a variety of soil types ranging from sand dunes as seen at Yeppoon to heavy
clays as in Sri Lanka. The majority of sites where this species occurs in Australia have free draining
soils and often the roots are exposed to sea water (e.g. Cardwell; Fig. 22) and salt spray in the coastal
regions. This species is also found in the coastal areas of Darwin and some plants occur in Kakadu National Park on sandy loam soils. The *Calophyllum* plants are found naturally amongst the coastal plant communities at Cardwell and in Cape York Peninsula. The majority of stands that we inspected were either planted or naturally established by seed that would have been dispersed in sea water. Given the range of habitats in which it occurs (Fig. 22) and the density of plants growing at certain locations, and especially at Bowen, this clearly suggests that this species can be grown as a plantation crop on a wide range of soil types. Non-occurrence of this species inland sheds doubt on its ability to tolerate drought. Examination of selected provenances of *Calophyllum* to drought, salinity and waterlogging tolerances will help assess its natural ability to cope with these stresses.
Soil properties of the sites on which *Calophyllum* naturally occurs in Queensland

The soil samples collected from various sites were analysed for pH, electrical conductivity, water extractable elements, exchangeable elements and DTPA extractable elements (micronutrients) (Fig. 23). The status of the soil for these elements will reflect on soil fertility and the variations observed between sites will indicate the potential of this species to cope with varying soil conditions. This information will be necessary to predict agronomic requirements and to identify habitat conditions in which this species can perform well.
Soil pH (1:5 H₂O) ranged from 6.0 to 8.8 amongst the samples collected from various locations (Fig. 4). The pH of CaCl₂ extract varied between 5.0 to 7.6, suggesting that this species can grow well on soils with a pH of 7 ± 1.5. The soil electrical conductivity (1:5 H₂O) ranged between 0.025 dS/m to 0.325 dS/m, indicating that this species can withstand poor to medium fertility soils. The majority of the sites, however, had a conductivity of 0.05 dS/m, indicating they were less fertile and non-saline. The low salinity of the substrate (except at Cardwell) and high sodium and chloride concentrations of the leaf (Fig. 23) indicate that most of the salts in the leaf would have come from sea breeze, rather than from the soil. The organic carbon content was low at most sites, except a few samples from Darwin that contained up to 3.8%. The nitrogen, phosphorus and sulphur concentrations were low, but potassium concentrations were reasonable. Aluminium concentration was high only at one site. Most soils in which Calophyllum occurred had a cation exchange capacity of 6 meq/100g and a calcium: magnesium ratio of 4. Only one site at Cardwell had high levels of sodium and chloride, but many others had acceptable levels. The site with high sodium and chloride also had higher sodium and chloride concentrations in the leaves (Fig. 24). The boron and DTPA extractible elements were low and varied between sites.

**Chemical composition of leaves**

*Calophyllum* possesses all essential attributes to be used as a plantation crop for biodiesel purposes or for medicinal uses. However, success in growing these plants in plantations depends on an understanding of the nutritional requirements of the plant. An examination of the foliar composition of the plants that occur naturally, and of the relationship between these concentrations and tree size and oil content of the fruit will help decide the type of nutrients to be used and the relative proportions of nutrients to be maintained in the fertilizer application schedule, if these plants are to be established in plantations.

Youngest fully expanded leaves were collected from trees grown in various locations and were analysed for mineral compositions. Figure 24 shows variations in leaf nutrient compositions of different provenances. Results show that the *Calophyllum* plants across the sites maintained similar levels of nitrogen (~ 1.2% dry wt) and phosphorus (0.08%), but they showed large variations in potassium (0.4–0.8%), magnesium (0.09–0.24%), calcium (0.8–1.4%) and sulphur (0.12–0.3%). Micronutrients such as boron, copper, iron, manganese and zinc were all at expected levels except for molybdenum which was very high in two of the three samples from Darwin. Site variations occurred in leaf micronutrient concentrations, with the plants found in Townsville containing higher levels of micronutrients than those in other parts. This may be due to intensive care given by the Townsville City Council as they have been established and maintained by the Council as street plants with well established grass underneath. The sodium and chloride concentrations also varied between samples, with the highest levels of chloride (0.24%) found in a sample from Bowen. Overall, no marked differences exist between provenances in leaf mineral concentrations, indicating the ability of this tree to grow well in a wide range of soils. The higher levels of sodium and chloride (0.2% and 0.1%, respectively) in the leaves indicate that they can tolerate salinity better than most agricultural crop plants. These levels also indicate that the leaves of *Calophyllum* are not affected by the salts contained in the sea breeze.
Figure 23. Soil pH, conductivity (dS/m), organic carbon (%), N, P, K, S, Al (mg/kg) and exchangeable Ca, Mg, K, Na, Al, cation exchange capacity (CEC; meq/100g), calcium to magnesium ratio, exchangeable sodium percentage (ESP), B, Cl and DTPA extractable Cu, Fe, Mn, Mo, Zn (mg/kg) of different soils on which Calophyllum plants naturally occur, or are planted as an ornamental plant. The soil samples were collected at 0-30 cm and 30-60 cm and the averages of these two depths are presented here.
Figure 23 contd... Soil exchangeable Na, Al, cation exchange capacity (CEC; meq/100g), calcium to magnesium ratio, exchangeable sodium percentage (ESP), B, Cl and DTPA extractable Cu, Fe, Mn, Mo, Zn (mg/kg) of different soils on which *Calophyllum* plants naturally occur, or are planted as an ornamental plant. The soil samples were collected at 0-30 cm and 30-60 cm and the averages of these two depths are presented here.
Figure 24. Leaf mineral concentrations of *Calophyllum inophyllum* samples collected from various locations in Queensland and Northern Territory. The Y axes of N, P, K, Ca, Mg, S, Na and Cl are in g/100 g dry weight (which is 10000 times higher than ppm), and those of B, Cu, Fe, Mn, Mo and Z are in ppm (which is mg/kg dry weight).
Leaf mineral concentrations of *Calophyllum inophyllum* samples collected from various locations in Queensland and Northern Territory. The Y axes of N, P, K, Ca, Mg, S, Na and Cl are in g/100 g dry weight (which is 10000 times higher than ppm), and those of B, Cu, Fe, Mn, Mo and Z are in ppm (which is mg/kg dry weight).

**Variations in fruit size and kernel attributes**

*Calophyllum* bears large number of fruits (Fig. 25). The fruit consists of exocarp, mesocarp, endocarp and kernel (see inset in Fig. 25). It is only the kernel that contains oil. The oil content of the kernel varies from 20% to 60%, depending on the provenance and the size of the fruit. Fruit bats are attracted to fruits when they become ripe. Fruits can be harvested from the trees, or they may be collected from the floor after they have dropped on the ground either after full maturity or after the fruit bats have eaten the flesh and dropped the remaining part of the fruit.

Assessment of the fruits collected from various locations indicates large variations in several fruit parameters. For example, fruit volume for Cardwell samples were 240 mL whereas the same for
Townsville samples were 180 mL (Fig. 26). Variations in fruit size could result from the total number of fruits held by the tree (the higher the number, the smaller the average fruit size), nutritional status of the tree, environmental conditions prevailing during fruit set and the season during which the sampling was undertaken. Since the fruits were collected only during one season, it is difficult to predict actual causes for such variations.

While the average fruit weight showed little variation, the fruit moisture content differed significantly between the provenances as well as between green and fallen fruits. Moisture content of green fruits was higher than those of fallen fruits for Cardwell samples. Higher moisture content of even the fallen fruits in Townsville, again suggests a better care received by these trees by the Townsville City Council. These results indicate that *Calophyllum* can respond to agronomic treatments such as irrigation and fertilizer application.

**Seed germination**

Two types of fruits were collected from the field: the ones fallen on the ground (Brown); and those picked from the tree or those that had just fallen and still had green skin (Green; see Fig. 27). The fruits were transported to the laboratory and were air dried for 1–2 weeks. The air dried fruits/kernels were germinated in pots containing washed river sand.

Two treatments were imposed on Brown and Green samples of fruits. In the first treatment, whole fruits were sown, and in the second, kernels were separated and sown.

Seed germination commenced three weeks after sowing and the number of seedlings emerging either from the fruits or from the kernel was counted at regular intervals. The results after 6 months of sowing are shown in Figure 27. Overall, Green fruits showed lower germination percentage compared to the Brown fruits, as some of the Green fruits were probably still immature. Comparison between whole fruits and the kernels also showed marked differences, with the kernels showing higher germination than the whole fruits. The fate of sown fruits that did not germinate is currently being investigated. These results will have an implication for seed germination and conservation of this species in the wild as *Calophyllum* has been classified as a recalcitrant species; as its germination declines or completely fails when the seed moisture content reaches below 20%.

**Variations in kernel oil content**

The oil content of up to 20 randomly selected kernels from each of the three provenances is shown in Figure 28. Large variations in kernel oil content were noted both between the provenances as well as between the kernels of the same provenance. While both Townsville and Cardwell provenances had ca. 24% oil, the kernels from Yeppoon had only ca. 12%. This is a significant observation, as oil content of the kernel and fruit yield of the tree is the determinant for the practicality of this species being used as a potential biodiesel plant. The causes for such marked variations could be the stage at which the fruits were collected (most fruits from Yeppoon were picked from the trees whereas those from Townsville and Cardwell were collected from the ground), nutritional status of the tree and the number of fruits held by the tree during that season.
Figure 26. *Calophyllum inophyllum* fruit size (fruit volume in mL/fruit, dry weight in g/fruit), and moisture content (%) parameters of the samples collected from various locations in Queensland.
Figure 27. Effect of removing husk on seed germination, and the variation between provenances in seed germination: 6 months after germination. CBeach= Cardwell beach, CTree=Cardwell city.
Conversion of kernel oil into biodiesel via transesterification

*Calophyllum* oil is highly acidic (44 mg KOH) and highly viscous (72 cSt at 40 °C). Conventional conversion protocols yield inferior quality FAME or biodiesel. Procedures of converting *Calophyllum* oil have been optimised (reaction temperature, reaction time, volumetric ratio of methanol (MeOH): oil and catalysts) and now the oil has been successfully converted into biodiesel by a 4 stage modified transesterification protocol (Fig. 29; Hathurusingha et al. 2009). This leads to reduction of free fatty acid (FFA) from 22% to less than 2%. The conversion rate from oil to biodiesel for *Calophyllum* ranges from 0.8–0.9 depending on the procedures adopted and the source of oil used. Further studies on assessing seed oil composition (various fatty acids) and the derived biodiesel are currently underway (Fig. 30).
Figure 29. Successful conversion of *Calophyllum inophyllum* oil into biodiesel. (A; separation of impurities, B; Initialising Phase separation, C; Showing oil (left) and biodiesel (right)) (photos: Subhash Hathurusingha).

![Figure 28: Fatty acid profile of Calophyllum inophyllum.](image)

Figure 28. Fatty acid profile of *Calophyllum inophyllum*.

Table 5. Kernel oil content, acid value, density and viscosity of the oil of *Calophyllum inophyllum*, with the estimated biodiesel conversion potential of two methods used.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>46.51±4.5</td>
<td>22.0</td>
<td>0.97</td>
<td>72.0</td>
<td>85%</td>
<td>96%</td>
</tr>
</tbody>
</table>
Engine performance

The *Calophyllum* oil was extracted using a cold press (Fig. 2) after numerous trials, and the bulk oil was mixed with mineral diesel at 0 (neat diesel), 5 and 20%. The neat and blended *Calophyllum* biodiesels were tested for various parameters. This study revealed that biodiesel from *Calophyllum* performed as well as the mineral diesel. It was also noticed that the engine vibration was low when *Calophyllum* biodiesel was used as compared with the use of mineral diesel (Hathurusingha et al. 2009).

Potential role of *Calophyllum* in biodiesel production

Similarities in the performance of *Calophyllum* biodiesel and mineral diesel, reasonable production of oil (3000–4000 litres/ha/yr) from the trees, availability of a suitable method (Hathurusingha et al. 2009) to convert this oil into biodiesel and the ability of this species to provide other benefits such as medicine from the bark, fertilizer value of the oil cake and timber production at the end of its life cycle and most importantly, its ability to grow on marginal soils, all indicate that this species can be readily exploited to produce biodiesel in CQ as well as in northern Australia.

The presence of large variability between provenances (Fig. 31) for both oil content and fatty acid composition also indicates that further research is needed to select the best genotypes. At present, very little is known about agronomic responses of this species. Hence, studies are required to optimise planting spacings and fertilizer requirements, and post harvest processing protocols.

Establishment of plantations using high fruit yielding genotypes from different locations will not only help test their variability, but it will also help produce superior genotypes for commercial use.

In summary, this study has evaluated various parameters concerning the use of *Calophyllum inophyllum* in biodiesel production, particularly from the point of view of selecting superior genotypes for use by biodiesel enthusiasts, and to test the feasibility of converting *Calophyllum* oil into biodiesel, followed by the evaluation of the derived biodiesel for its fuel efficiency and environmental benefits. To the best of our knowledge, this has been the first study in Australia where this species is being evaluated for biofuel production. The study has also assisted a PhD student in strengthening his research topic. Further studies are underway to test the full potential of this species as a biodiesel feedstock.
2 Aleurites moluccana (Candle nut tree)

The Candle nut tree occurs in northern and eastern Australia (Fig. 32). It is also widespread throughout the world, with distribution in South East Asia, Hawaii and India. The tree grows up to 25 m, with a medium to dense canopy. Leaves, bark and fruits are used for medicinal purposes or as food. The roasted kernels are consumed, and the oil is an irritant and laxative. Because of the high oil content, the kernels are powdered and used in candle making when candles are not readily available. Another similar looking species, A. rockinghamensis, produces seeds that are toxic, so proper identification of the species is critical.

This species is monoecious. The flowers are white, fragrant and are borne in branched terminal panicles 10–15 cm long. Each panicle has about 60 flowers each 12 mm long. The flowering season is from January to March. Fruits are globular, brown, 5–8 cm in diameter and contain 1–2 seeds (nuts). Each nut is spherical, up to 4 cm in diameter, of a mottled grey to nearly black colour, with a hard brittle shell. The kernel (within the nut) contains oil which burns easily, hence the term ‘candle nut’. Fruiting occurs from March to May.

This is a fast growing species; thrives on a wide range of soils but prefers light and medium textured soils. It attains a height growth of 1–1.5 m a year and produces up to 7000 fruits per tree (Fig. 32).

The tested samples of kernels contained 47% oil primarily made up of linoleic, linolenic and oleic acids (Table 6; Fig. 33). The oil can be converted using the modified method with a conversion efficiency of 97–107%. Presence of high amounts of linolenic acid (>12%) might pose problems with its use as a biodiesel (European Standard Organization 2003).

*Cultivation:* The Candle nut tree can be established in open sun as an upper-storey species.

Figure 30. Growth habit, kernels and distribution map of Aleurites moluccana.
Figure 31. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of *Aleurites moluccana*.

Table 6. Kernel oil content, acid value, density and viscosity of the oil of *Aleurites moluccana*, with the estimated biodiesel conversion potential of two methods used.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>46.73±8.23</td>
<td>0.63±0.06</td>
<td>0.93</td>
<td>24.93±0.12</td>
<td>97±2.3</td>
<td>107±1.5</td>
</tr>
</tbody>
</table>
3 Syagrus romanzoffiana (Queen Palm)

The Queen palm is a naturalised species and is a widely cultivated ornamental plant in Australia and overseas. It originates from South America and tolerates tropical and temperate climates. It grows up to 20 m tall and bears fruits in panicles. Each inflorescence weighs about 10 kg (dry weight). The fruit contains husk, hard shell and a kernel. At present it occurs widely in the subtropical region (Fig. 34; Weeds Australia 2010), but is expected to spread rapidly into the wet tropics of Queensland and the Northern Territory. Because of the fast spreading ability, this has been identified as a species with high weed potential.

The Queen palm grows in a wide range of soils from coastal sands to heavy cracking clay soils. It is grown extensively in the city of Rockhampton and to the west as far as Alpha where the temperatures reach sub zero to high 40s and the rainfall ranges from 400 mm to 2000 mm.

The Queen palm resembles coconut in many respects, but bears small fruits which do not contain free water, unlike coconut. If there is a good supply of water, the Queen palm produces fruits throughout the year. In other situations, it fruits twice a year. The fruits can be hand harvested and fermented to remove the husk, or they can be dried to separate the kernel from the shell and husk. Since the shell is very hard, separation of the kernel from shell could be a challenge.

The shell and kernel of the seed can be separated before extracting the oil, or the entire seed can be ground and used in oil extraction. The first method is preferable to minimize the tendency of the shell to soak up the oil during extraction, but this task requires specially designed machines.

The kernel contains 41–47% oil (Table 7) which is colourless and has a low acid value with a viscosity of 15.5 cSt. The oil can be readily converted into biodiesel either by the base saturation method or by using the modified method. Both these methods convert the oil into biodiesel at 105–111% conversion efficiency. The oil comprises mainly oleic and lauric acids (Fig. 35).

Cultivation: Queen Palm is suitable for establishment as the canopy species as a monoculture plant. Since it can support plants in the understorey, it can also be grown in mixed culture.
Figure 33. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of *Syagrus romanzoffiana*.

Table 7. Kernel oil content, acid value, density, viscosity and biodiesel conversion rates of *Syagrus romanzoffiana*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.64±3.78</td>
<td>3.49±0.06</td>
<td>0.94</td>
<td>15.50±0.06</td>
<td>105±0.3</td>
<td>111±3.5</td>
</tr>
</tbody>
</table>
4  *Murraya exotica* (Mock orange)

This is one of the most popular plants amongst home gardeners in CQ. *Murraya* and *Duranta* are widely used as hedge plants or ornamentals. *Murraya exotica* is a naturalised species that usually grows up to 3 m tall. It bears abundant numbers of flowers which have a very fragrant smell. It also bears fruits prolifically. The fruits mature in two seasons (autumn and spring). It is drought tolerant and grows in a wide range of soil types. It can also tolerate partial shading and copes with regular pruning (Fig. 36).

The fruits turn red when ripe and can be picked and dried before extracting the oil. The fruits can also be fermented to remove the skin. The seed contains 22% oil which is dominated by linoleic, elaidic and palmitic acids (Fig. 37). The oil has a viscosity of 19.5 cSt, low acidity and can easily be converted to biodiesel using the base saturation method, with a biodiesel recovery of 96% (Table 8).

*Cultivation:* This can be grown in open sun or used as an understorey species on a wide range of soils. However, its fruiting productivity is determined by moisture availability.

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**Figure 34.** Growth habit, fruits and distribution map of *Murraya exotica*. Source: Weeds Australia: [http://www.weeds.org.au/](http://www.weeds.org.au/).
Figure 35. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of *Murraya exotica*.

Table 8. Kernel oil content, acid value, density, viscosity and biodiesel conversion rates of *Murraya exotica*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.86±0.36</td>
<td>2.14±0.05</td>
<td>1.11</td>
<td>19.47 ± 0.03</td>
<td>96± 1.9</td>
<td>n/a</td>
</tr>
</tbody>
</table>
5  **Cordyline manners-suttoniae (Cordyline)**

*Cordyline* is a palm-like plant that usually grows up to 2 m, often extending up to 4 m tall (Fig. 38). It normally grows in rainforests in gullies along stream lines. It produces long panicles on which berries of 1–1.5 cm are borne. On maturity, the berries turn red.

The fruits are very easy to harvest. They can be fermented to extract seeds or the whole fruit can be dried and ground before extracting the oil.

The seeds contain up to 12% oil which has low acid value and density, with a viscosity of 20.4 cSt. The oil is made up of linoleic and oleic acids (Fig. 39). The oil can be easily converted to biodiesel by the base saturation method. A conversion of 101% can be achieved by this method (Table 9).

*Cultivation:* *Cordyline* is very resilient to shading and the leaves become scorched in summer. Hence this is an ideal species for establishment as an understorey species. Although it can survive under dry conditions, fruit production requires irrigation.

![Figure 38. Growth habit, fruits, kernels and distribution map of Cordyline manners-suttoniae.](image)
Figure 39. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of *Cordyline manners-suttoniae*.

Table 9. Kernel oil content, acid value, density, viscosity and biodiesel conversion (%) rates of *Cordyline manners-suttoniae*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.84 ± 1.77</td>
<td>15.41 ± 0.07</td>
<td>0.85</td>
<td>20.43 ± 0.03</td>
<td>101</td>
<td>98 ± 1.2</td>
</tr>
</tbody>
</table>
Grevillea banksii (Grevillea)

Grevillea is a shrub that commonly occurs on coastal dunes and sand plains, heath lands and eucalypt communities. It is renowned for growth on disturbed sites such as road sides. Several cultivars and hybrids have been produced to improve the flowering habit. These cultivars also bear large number of fruits which can be harvested and dried to obtain seeds (Fig. 40). The seeds contain 15% oil which is primarily dominated by oleic acid (50%). The oil also contains a variety of other fatty acids (Fig. 41) which are not common in most other species. The oil has low acid value and has a density of 0.93 (Table 10).

*Cultivation:* This species is drought tolerant and can be grown open field conditions in free draining soils.

Figure 36. Growth habit, seeds and distribution map of *Grevillea banksii.*
Figure 37. Biodiesel (Method 2), oil and fatty acid profile of *Grevillea banksii*.

Table 10. Kernel oil content, acid value, density, viscosity and biodiesel conversion (%) rates of *Grevillea banksii*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.85 ± 1.21</td>
<td>13.82 ± 0.03</td>
<td>0.93</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>
7  *Elaeocarpus grandis* (Blue quandong)

This is a tall tree that grows up to 30 m and usually occurs in the rainforests of eastern and northern Australia. It produces fruits on large racemes. The fruits are round and blue with a soft skin and corrugated shell inside which a tiny kernel is found. The shell is very hard to break (Fig. 42).

The kernel contains 38% oil (Table 11) but the proportion of the kernel to seed is very low. The oil contains oleic, palmitic and linoleic acids (Fig. 43). The oil can be converted to biodiesel using modified method.

*Cultivation:* Queensland blue quandong can be grown in open sun in a range of soils. Since the branches are very brittle, harvesting techniques used should minimise the damage to the trees.

*Figure 38. Growth habit, fruits, kernels and distribution map of* *Elaeocarpus grandis.*
Figure 39. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of *Elaeocarpus grandis*.

Table 11. Kernel oil content, acid value, density, viscosity and biodiesel conversion (%) rates of *Elaeocarpus grandis*.

<table>
<thead>
<tr>
<th>Kernel Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>398±0.25</td>
<td>8.70</td>
<td>0.92</td>
<td>24.60±0.06</td>
<td>110</td>
<td>102</td>
</tr>
</tbody>
</table>
8  **Ochna serrulata** (Ochna)

Ochna is a shrub that grows up to 3 m (Fig. 44). It is propagated mostly by birds, so populations of these plants are found under tall trees. This plant produces spectacular petals with free ovaries. On maturity, the seeds turn black. The seeds can be dried before extracting oil. The seeds contain 31% oil and are dark in colour. The oil is made up of palmitic, oleic and linoleic acids (Fig. 45). The oil has low acid value, low density and a viscosity of 15.5 cSt (Table 12). The oil can be effectively converted to biodiesel using Method 1.

*Cultivation:* Ochna is a shade tolerant plant, although its fruit production requires open sun. This is drought tolerant and can be established both in open field as well as an understorey species.

![Figure 40. Growth habit, fruits, kernels and distribution map of Ochna serrulata.](image)
Figure 41. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of *Ochna serrulata*.

Table 12. Kernel oil content, acid value, density, viscosity and biodiesel conversion (%) rates of *Ochna serrulata*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value (g/ml)</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.16</td>
<td>6.81±0.03</td>
<td>0.87</td>
<td>15.53±0.03</td>
<td>97±8.3</td>
<td>86±4.1</td>
</tr>
</tbody>
</table>
Brachychiton bidwillii is a shrub growing up to 4 m tall (Fig. 46). It is deciduous and bears spectacular flowers. The fruits are follicles borne on the branches and they contain 20–30 pea sized seeds. Seeds contain 15% oil which is red in colour. The oil is made up of oleic, linoleic and palmitic acids (Fig. 47) and is characterised by high acid value and high viscosity (Table 13). The oil cannot be converted into biodiesel using the standard base saturation method. However, it can be readily converted into biodiesel using the modified method (Method 2) which yields ca. 100% conversion (Table 13).

*Cultivation:* This species can be grown in open sun and can also tolerate partial shading. Thus it is suitable for mixed planting on a wide range of soil types.

Figure 42. Growth habit, fruits, distribution map and seeds of *Brachychiton bidwillii.*
Figure 43. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of *Brachychiton bidwillii*.

Table 13. Kernel oil content, acid value, density, viscosity and biodiesel conversion (%) rates of *Brachychiton bidwillii*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.15±1.57</td>
<td>25.80±0.14</td>
<td>0.90</td>
<td>23.03±0.09</td>
<td>ns</td>
<td>103±1.4</td>
</tr>
</tbody>
</table>
10 Koelreuteria formosana (Chinese rain tree)

The Chinese rain tree is a naturalised tree that grows up to 25 m high. It produces bipinnate leaves and can tolerate dry conditions. The inflorescences are very spectacular and contain ellipsoid capsules (Fig. 48). The entire tree will be covered with inflorescences when in bloom. Capsules can be dried and the seeds can be separated using a thresher. Because of its aggressive growth habit, this is classed as a weed. The seeds contain 22% oil (Table 14) which has low acid value and is comprised of eicosenoic acid and oleic acids (Fig. 49). The oil can be readily converted into biodiesel using the standard base saturation method (Table 14).

*Cultivation:* Once established this species can thrive without irrigation. It can be grown on a wide range of soils as an upper storey species either in monoculture or in mixed culture.

Figure 48. Growth habit, fruits, kernels and distribution map of Koelreuteria formosana.
Figure 49. Biodiesel (Method 1), oil and fatty acid profile of Koelreuteria formosana.

Table 14. Kernel oil content, acid value, density, viscosity and biodiesel conversion (%) rates of Koelreuteria formosana.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.17±0.51</td>
<td>1.57±0.03</td>
<td>0.92</td>
<td>23.23±0.3</td>
<td>111±0.9</td>
<td>n/a</td>
</tr>
</tbody>
</table>
11 **Santalum album (Sandalwood)**

Sandalwood is a medium sized tree growing up to 8 m. While this species occurs widely in many countries, including India, natural stands of this species are also found in the Northern Territory (Fig. 50). This species has been used for sandalwood oil in cosmetics and soap manufacturing. It is a hemi-parasitic tree, occurring in semi-arid areas of India, the South Pacific and the northern coast of Australia.

This species grows normally in sandy soils or stony terrains. It produces urn shaped fruits which contain 25% oil (Table 15). The amber coloured oil is primarily comprised of arachidonic acid (80%) and oleic acid (10%) (Fig. 51). The oil is very viscous (120 cSt) and has low acid value and density (Table 15).

The oil can be easily converted into biodiesel either by base saturation or by the modified method with 95–100% conversion rate.

*Cultivation:* This is a parasitic plant requiring a host plant during its establishment. It should be established in the open sun, although it can tolerate partial shading from other species. Large plantations of sandalwood have been established in Western Australia for timber production which can be used to extract sandalwood oil. The by-product (fruits) can be used to produce biodiesel. A photograph of the plant can be found at: http://www.arkive.org/media/54/549425A4-E24D-45D6-9A10-15CBCCAACD9C/Presentation.Large/photo.jpg

![Figure 44. Distribution map and fruits of *Santalum album*.](image-url)
Figure 45. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of Santalum album.

Table 15. Kernel oil content, acid value, density, viscosity and biodiesel conversion (%) rates of Santalum album.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.49±3.23</td>
<td>6.42±0.09</td>
<td>0.79</td>
<td>120.17±0.09</td>
<td>95±2.1</td>
<td>101±2.0</td>
</tr>
</tbody>
</table>
12 **Argemone mexicana** (Mexican poppy)

The Mexican poppy is an herbaceous plant that grows up to 1 m tall in disturbed and neglected lands (Fig. 52). This has been classified as an environmental weed in Australia. It produces capsules that contain several seeds. The whole plant can be harvested and dried to separate the seeds. Capsules break open on drying to release seeds which can be separated from the plant by sieving (Fig. 52).

The seeds contain 24% oil (Table 16) which is reddish in colour and is dominated by linoleic and oleic acids (Fig. 53). The oil has very high acid value (141). Despite its high acidity, the oil can be converted to biodiesel with a conversion efficiency of 97%.

*Cultivation: Argemone mexicana* has been declared a weed, as it grows well on disturbed soils where other species cannot grow. It also grows in open sun under a wide range of soils, provided competition from other species is kept to a minimum. Thus its cultivation, if any, requires careful weed management strategies. Ideal sites are those disturbed by quarrying, mining or other activities.

![Figure 46. Growth habit, fruits, seeds on the ground and distribution map of Argemone mexicana.](image)
Figure 47. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of *Argemone mexicana*.

Table 16. Kernel oil content, acid value, density, viscosity and biodiesel conversion rates of *Argemone mexicana*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.38±5.0</td>
<td>141</td>
<td>0.89</td>
<td>12±0.06</td>
<td>97±0.5</td>
<td>86±8.6</td>
</tr>
</tbody>
</table>
13  *Petalostigma pubescens* (Quinine bush)

The quinine bush grows amongst woodland species and riparian vegetation and is able to tolerate partial shading. Although most common in free-draining soils, it can tolerate a wide range of soil conditions. Quinine bush has been used as a medicinal plant by Indigenous communities.

The plant bears large quantities of fruits (Fig. 54) which turn orange on maturity. On drying, the fruits burst open rigorously and in this process, they make a loud sound if enclosed in containers. Fruits must be collected before they fully mature. The seeds contain 21% oil (Table 17) which is made up of oleic and linoleic acids (Fig. 55).

*Cultivation*: The quinine bush usually occurs in sandy coastal soils as an understorey species. It is an ideal species for mixed planting, although it can be more productive in open field conditions.

![Figure 48. Growth habit, fruits, kernels and distribution map of *Petalostigma pubescens*](image)
Figure 49. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of *Petalostigma pubescens*.

Table 17. Kernel oil content, acid value, density, viscosity and biodiesel conversion rates of *Petalostigma pubescens*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.13±2.74</td>
<td>9.78±0.06</td>
<td>0.94</td>
<td>29.80±0.12</td>
<td>97±0.3</td>
<td>102±2</td>
</tr>
</tbody>
</table>
14 *Brachychiton acerifolius* (Flame tree)

Also known as the Flame tree, this is a popular street tree in Queensland and NSW. It naturally occurs in subtropical and tropical rainforests. The Flame tree is popular for its dark green foliage and spectacular flowering after it sheds leaves (Fig. 56). This species grows on a wide range of soils, but is suitable for high rainfall areas unlike other species of *Brachychiton*. The fruits are large and contain 10–15 seeds. The pods can be harvested when they turn coppery brown. Extra care should be taken in separating the seeds, as the hair associated with the seeds can cause irritation.

The seeds contain 20% oil (Table 18) which can be converted to biodiesel using the modified method only. The standard base saturation method does not seem to be effective in its conversion (Fig. 57). The oil contains oleic, linoleic, palmitic and stearic acids.

*Cultivation:* The Flame tree can be established as an upper storey species.

![Figure 50. Growth habit, fruits, kernels and distribution map of *Brachychiton acerifolius*.](image)
Figure 51. Biodiesel (Method 1; left, Method 2; right) and fatty acid profile of *Brachychiton acerifolius*.

Table 18. Kernel oil content, acid value, density, viscosity and biodiesel conversion (%) rates of *Brachychiton acerifolius*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.9±2.17</td>
<td>8.18±0.06</td>
<td>0.89</td>
<td>22.33±0.09</td>
<td>ns</td>
<td>96±7.9</td>
</tr>
</tbody>
</table>
15 **Jagera pseudorhus (Jagera)**

Commonly known as jagera, this species occurs in eastern Australia amongst woodland species. Jagera grows mostly in free-draining soils, but is widespread in a range of soils. Can also tolerate partial shading, but the productivity may be higher in open sun. It bears large quantities of fruits in bunches (Fig. 58) that are very easy to harvest. Seed separation is also relatively easy. Suitable care should be taken in processing the seeds as the fine hair can be irritating.

The seeds contain 34% oil (Table 19) which has low acid value and mainly comprised of eicosenoic and oleic acids (Fig. 59). The oil can easily be converted to biodiesel using the base saturation method (90% conversion) or by Method 2 (94% conversion).

*Cultivation:* Jagera is suitable for establishment in open field conditions in free-draining soils. This species can tolerate very dry conditions, but the fruit production is higher where regular moisture availability exists.

![Figure 58. Growth habit, fruits, kernels and distribution map of *Jagera pseudorhus.*](image-url)
Figure 59. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of *Jagera pseudorhus*.

Table 19. Kernel oil content, acid value, density, viscosity and biodiesel conversion (%) rates of *Jagera pseudorhus*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.01±0.62</td>
<td>5.11±0.06</td>
<td>0.92</td>
<td>15.47±0.03</td>
<td>90±1.5</td>
<td>94±2.1</td>
</tr>
</tbody>
</table>
16  *Ricinus communis* (Castor oil seed)

This is a shrub that grows up to 3 m tall. It occurs throughout Australia on disturbed sites and in riparian habitats. Castor can grow in a wide range of soils, and some improved cultivars can also tolerate drought conditions. The Australian cultivars produce variable quantities of seeds but their oil content is very low compared to those of cultivated forms. The fruits are easy to harvest and the seeds separate readily following drying (Fig. 60).

The seeds contain 20% oil, which is dense and has high viscosity. The oil comprises of ricinolic and linoleic acids (Fig. 61, Table 20)

*Cultivation:* Castor has been declared as an environmental weed in Australia. However, it is widely cultivated in Asia as an oil seed crop and shade plant for ginger production. It is highly drought tolerant and grows well in degraded soils. While the wild forms are perennial, annual cultivars are also available which can yield much more oil than the local varieties, and contain higher oil percentages.

*Figure 52. Growth habit, fruits, distribution map and seeds of* *Ricinus communis*
Figure 53. Oil and fatty acid profile of *Ricinus communis*. Note: ricinolic acid corresponds to 26.47 min separation.

Table 20. Kernel oil content, acid value, density, viscosity and biodiesel conversion (%) rates of *Ricinus communis*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.55±1.03</td>
<td>5.60</td>
<td>0.94</td>
<td>95.93±0.07</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
17 **Atalaya hemiglauca (Whitewood)**

Referred to as ‘whitewood’ and occurring over a large area in central and northern Australia (Fig. 62), *Atalaya hemiglauca* grows in a wide range of soils and rainfall zones. It is a highly drought tolerant species and produces large quantities of fruit. The fruits can be used in oil extraction, or the seeds may be separated and then used in oil extraction.

The fruits contain 15–20% oil (Table 21) which comprises of oleic and eicosenoic acids (Fig. 63), and an acid value of 13.9 and the density of 1.02. Further assessment needs to be done for its conversion to biodiesel.

*Cultivation: Atalaya* is a highly drought tolerant species. It grows well in a wide range of soils in CQ. It requires open sun.

![Figure 62. Growth habit, fruits, distribution map and seeds of *Atalaya hemiglauca*.](image)
Figure 54. Oil and fatty acid profile of *Atalaya hemiglauca*.

Table 21. Kernel oil content, acid value, density, viscosity and biodiesel conversion rates of *Atalaya hemiglauca*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.62±5.53</td>
<td>13.86±0.43</td>
<td>1.02</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
**18 Dianella caerulea (Blue berry lily)**

This is a perennial lily which grows up to 50–130 cm tall. It is rhizomatous, forming mats or clumps of diameter 30–40 cm. The fruits are blue berries borne on a long stalk. The berries are 7–12 mm long and contain small seeds. Fruits are soft, pleasant and are edible (Fig. 64).

*Dianella* occurs in the woodlands and forests amongst grasses. Although it can grow on a wide range of soils, it is commonly found in sandy soils.

The fruits can be harvested and seeds extracted following fermentation or drying. The seeds (Fig. 64) contain 19% oil (Table 22) which has low acid value and is primarily made up of linoleic and oleic acids (Fig. 65). The oil can be readily converted into biodiesel with a conversion efficiency of 100% (Table 22) using the base saturation method (Method 1).

*Cultivation:* *Dianella* can tolerate partial shading and as it grows amongst grasses, it is suitable for establishment as an understorey species.

![Growth habit, seeds and distribution map of Dianella caerulea.](image-url)
Figure 56. Biodiesel (Method 1) and oil of *Dianella caerulea*.

Table 22. Seed oil content, acid value, density, viscosity and biodiesel conversion (%) rates of *Atalaya hemiglauca*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value (g/ml)</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1 (%)</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.66 ±2.6</td>
<td>3.74 ±0.08</td>
<td>0.89</td>
<td>14.37 ±0.03</td>
<td>100 ±0.1</td>
<td>n/a</td>
</tr>
</tbody>
</table>
19  **Pongamia pinnata** (Karanja)

*Pongamia* is one of the most heavily researched and trialed species both in Australia and India for its biodiesel potential. While the fundamental research has been carried out by the University of Queensland, a private company (The Australian Phytofuel Ptd Ltd) has been testing its practical feasibility over a wide range of site and soil conditions.

*Pongamia* grows up to 20 m tall and usually occurs in tropical Australia in high rainfall areas (Fig. 66). It can also grow in inland and drier areas, subject to availability of sub-soil moisture. It can tolerate a wide range of soil conditions, including saline and acidic soils. One of the unique features of this species is that it can fix nitrogen, thus having a special value in mixed cropping. However, it tends to shade heavily, so no understorey species may be established. *Pongamia* produces pods that contain large seeds. The seeds contain 22–60% oil (Table 23) which comprises of mostly oleic and linoleic acids (Fig. 67). The oil has low acid value and can readily be converted to biodiesel using the base saturation method, with a conversion efficiency of 99%.

*Cultivation: Pongamia* is drought tolerant and salt tolerant and it can withstand some degree of shading. It is a nitrogen fixing plant requiring little care after establishment. Production, however, will be higher in sites having high available sub soil moisture. This species can be grown in monoculture; however, this will be an excellent species for mixed planting with palms, as it can fix nitrogen. No understorey species can be established, as it produces a dense canopy.

![Figure 57. Growth habit, fruits, distribution map and seeds of *Pongamia pinnata*.](image)

---

82
Figure 58. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of *Pongamia pinnata*.

Table 23. Kernel oil content, acid value, density, viscosity and biodiesel conversion (%) rates of *Pongamia pinnata*.

<table>
<thead>
<tr>
<th>Seed Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.68±3.28</td>
<td>2.31±0.02</td>
<td>0.90</td>
<td>20.17±0.03</td>
<td>99±1.3</td>
<td>n/a</td>
</tr>
</tbody>
</table>
20 **Cocos nucifera** (Coconut)

The coconut is a naturalised species in Australia and grows along eastern tropical coasts. It is also planted as a road side palm, both inland as well as on the coast. In CQ, it grows well along the coast as well as in gardens and public amenity areas. This species is extremely easy to grow and requires very little care after establishment, if grown as an ornamental species. However, if established as a plantation, this species needs to be managed to achieve economical gains. Growth rates of 30–50 cm per year for over 40 years can be expected. Coconut produces a canopy of 8–9 m diameter (Fig. 68) and allows a variety of species to grow underneath. As a result, coconut has been used extensively in agroforestry. In CQ this species is suitable for rainfall zones of 800–2000 mm.

In CQ, city councils are finding this species a nuisance due to health and safety issues. The fronds and fruits drop frequently, posing a danger to pedestrians. As a result, planting of this species has been discontinued. Furthermore, some city councils have invested resources in building protective cages to collect fallen fruits to minimise damage to the public.

The very fact that this species grows well in coastal areas, tolerates salt spray, and thrives well on sandy soils and saline soils, indicates that this is a good candidate as far as growth is concerned. Its ability to bear large numbers of fruits that contain oil-rich endosperm makes it attractive as a biodiesel feedstock. Since coconut oil can be used in cooking and coir can be used in the nursery industry, the economics of coconut will be stronger as a food crop than as a biodiesel plant at the current price of biodiesel. This situation may change in the future, and hence the listing of this species for CQ.

The kernel of the coconut weighs approximately 200 g and contains 50% oil (Table 24). The oil is thin and transparent and is characterised by low acidity and viscosity (Table 24). The oil is made up of lauric and myristic acids, with some quantities of palmitic and oleic acids and it solidifies at room temperature (Fig. 69). The oil can easily be converted into biodiesel by either the base saturation method or the modified method. The conversion rate is ca. 103–110%.

*Cultivation:* Coconut is suitable for establishment in open field conditions in free-draining as well as heavy soils. It can tolerate very dry conditions, but the fruit production can only occur on soils that have high sub-soil moisture availability.

*Figure 68. Growth habit, fruits, kernels and distribution map of Cocos nucifera.*
Figure 69. Biodiesel (Method 1; left, Method 2; right), oil and fatty acid profile of Cocos nucifera.

Table 24. Kernel oil content, acid value, density, viscosity and biodiesel conversion (%) rates of Cocos nucifera.

<table>
<thead>
<tr>
<th>Kernel Oil (%)</th>
<th>Acid Value</th>
<th>Density (g/ml)</th>
<th>Viscosity (cSt)</th>
<th>Conversion 1</th>
<th>Conversion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.81 ± 1.09</td>
<td>0.53 ±0.4</td>
<td>0.91</td>
<td>14.55±0.12</td>
<td>103 ±1.2</td>
<td>110 ±3.0</td>
</tr>
</tbody>
</table>
Implications and Recommendations

This project has tested over 200 species/provenances of Australian native and naturalised species for their seed/kernel oil content. The species that contained appreciable amounts of oil in their seeds/kernels, and those that can produce reasonable quantities of seeds were examined for biodiesel conversion. The oils of the 20 selected species were also converted to biodiesel using the base saturation method (Method 1) and the modified method (Method 2; Hathurusingha et al. 2009).

One of the 20 selected species (*Calophyllum inophyllum*) has been studied in detail for its provenance variations in (i) morphological characteristics, (ii) fruit characters, (iii) oil content, (iii) oil composition and (iv) biodiesel properties. The remaining species were also assessed for oil properties and biodiesel conversion potential.

Based on the measured seed/kernel oil content and estimated size of the mature plant and its predicted seed bearing potential, the oil yield per ha was calculated for each of the selected species that contained appreciable quantities of oil (ca. 10% or more).

Table 25 shows the estimated oil production potential of each species if they are established at the nominated spacings in CQ, particularly within 100 km from Rockhampton. The knowledge gained in the field and the concepts used by the macadamia and mango industries in the region were applied to estimate desirable spacings and in predicting seed yield. Generally, the above industries use narrower spacings than that occupied by plants that occur naturally in the wild. This narrower spacing will help increase per ha yields, as well as allowing for thinning, if needed.

The availability of data on optimal spacing, seed yield per plant, yield variability between locations and soil types and responses of plants to fertilizers and irrigation will determine the reliability of the oil yield estimated for each species (Table 25). Since much of the above information is lacking (except for *Calophyllum inophyllum*) for the species included in this study, those parameters were approximated based on field observations and on anecdotal notes obtained from literature. Because of these limitations, it is warned that the predictions shown in Table 25 are to be used with caution, and to be treated only as a guide.

Despite the limitations, the data shown in Table 25 will help draw some conclusions regarding relative potential of species for biodiesel production. Accordingly, the species are grouped into four categories:

- a. Species that have definite potential to be used as biodiesel feed stocks. These include: *Calophyllum inophyllum, Aleurites moluccana, Pongamia pinnata, Cocos nucifera* and *Santalum acuminatum*. These species can produce between 1280 to 3800 kg oil/ha/yr.

- b. Species that show biodiesel potential if they are used in mixed cropping, or they also produce other economic products such as timber or valuable oil cake. The species that belong to this category include: *Syagrus romanzoffiana, Santalum album, Ricinus communis, Atalaya hemiglauca, Argemone mexicana* and *Azadirachta indica* (500–1200 kg/ha/yr).

- c. Species that can only be viable as biodiesel feed stocks if the oil is a by-product of some other process (e.g. seed protein, medicine from the bark, or husk). The species include *Acacia holosericea, Dianella caerulea, Ochna serrulata, Brachychiton acerifolius, Petalostigma triloculare, Sterculia quadrifida, Cordyline manners-suttoniae, Alectryon conatus* and *Melia azedarach* (300–500 kg/ha/yr).

- d. The species that contain appreciable amounts of oil but will not produce sufficient quantity of seeds to become economically viable. These include: *Grevillea sp., Banksia sp., Petalostigma pubescens, Elaeocarpus grandis, Brachychiton bidwillii, Jagera pseudorhus, Murraya exotica* and *Ficus microcarpa* (<300 kg oil/ha/yr).
Table 25. Seed/kernel oil content, and estimated spacing, seed weight and oil yield of selected
native, naturalised and exotic species (27) that grow well in Central Queensland
region.

<table>
<thead>
<tr>
<th>Species</th>
<th>Spacing (m)</th>
<th>Plants/ha</th>
<th>Seed/kernel wt/pl (kg)</th>
<th>Seed or Kernel Oil Content g/g</th>
<th>Estimated oil yield kg/ha/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trees</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calophyllum inophyllum*</td>
<td>8 x 6</td>
<td>208</td>
<td>20.0</td>
<td>0.46</td>
<td>3833</td>
</tr>
<tr>
<td>Elaeocarpus grandis</td>
<td>6 x 5</td>
<td>333</td>
<td>2.00</td>
<td>0.40</td>
<td>266</td>
</tr>
<tr>
<td>Aleurites moluccana</td>
<td>8 x 5</td>
<td>250</td>
<td>20.00</td>
<td>0.47</td>
<td>2350</td>
</tr>
<tr>
<td>Pongamia pinnata</td>
<td>6 x 4</td>
<td>417</td>
<td>20.00</td>
<td>0.30</td>
<td>2500</td>
</tr>
<tr>
<td>Santalum album</td>
<td>5 x 4</td>
<td>500</td>
<td>5.00</td>
<td>0.25</td>
<td>625</td>
</tr>
<tr>
<td>Brachychiton acerifolius</td>
<td>4 x 3</td>
<td>833</td>
<td>2.00</td>
<td>0.20</td>
<td>333</td>
</tr>
<tr>
<td>Jagera pseudorhus</td>
<td>4 x 3</td>
<td>833</td>
<td>0.50</td>
<td>0.34</td>
<td>141</td>
</tr>
<tr>
<td>Petalostigma triloculare</td>
<td>3 x 2</td>
<td>1,667</td>
<td>1.00</td>
<td>0.19</td>
<td>316</td>
</tr>
<tr>
<td>Atalaya hemiglauca</td>
<td>3 x 2</td>
<td>1,667</td>
<td>2.00</td>
<td>0.16</td>
<td>533</td>
</tr>
<tr>
<td>Santalum acuminatum</td>
<td>5 x 3</td>
<td>667</td>
<td>6.00</td>
<td>0.32</td>
<td>1280</td>
</tr>
<tr>
<td>Sterculia quadrifida</td>
<td>5 x 3</td>
<td>667</td>
<td>3.00</td>
<td>0.20</td>
<td>400</td>
</tr>
<tr>
<td>Alectryon conatus</td>
<td>4 x 3</td>
<td>833</td>
<td>2.00</td>
<td>0.28</td>
<td>466</td>
</tr>
<tr>
<td>Azadirachta indica</td>
<td>6 x 4</td>
<td>417</td>
<td>10.00</td>
<td>0.18</td>
<td>750</td>
</tr>
<tr>
<td>Melia azedarach</td>
<td>6 x 4</td>
<td>417</td>
<td>10.00</td>
<td>0.07</td>
<td>312</td>
</tr>
<tr>
<td>Ficus microcarpa var Ben*</td>
<td>8 x 5</td>
<td>250</td>
<td>1.00</td>
<td>0.18</td>
<td>90</td>
</tr>
<tr>
<td>Grevillea banksia</td>
<td>2 x 2</td>
<td>2,500</td>
<td>0.50</td>
<td>0.14</td>
<td>175</td>
</tr>
<tr>
<td>Cordyline manners**</td>
<td>1 x 1</td>
<td>10,000</td>
<td>0.10</td>
<td>0.16</td>
<td>480</td>
</tr>
<tr>
<td>Syagrus romanzoffiana*</td>
<td>6 x 4</td>
<td>417</td>
<td>2.50</td>
<td>0.42</td>
<td>875</td>
</tr>
<tr>
<td>Cocos nucifera</td>
<td>8 x 5</td>
<td>250</td>
<td>16.00</td>
<td>0.51</td>
<td>2040</td>
</tr>
<tr>
<td>Shrubs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ochna serrulata</td>
<td>2 x 1.5</td>
<td>3,333</td>
<td>0.40</td>
<td>0.31</td>
<td>413</td>
</tr>
<tr>
<td>Petalostigma pubescens</td>
<td>2 x 1.5</td>
<td>3,333</td>
<td>0.40</td>
<td>0.21</td>
<td>280</td>
</tr>
<tr>
<td>Brachychiton bidwillii</td>
<td>2 x 1.5</td>
<td>3,333</td>
<td>0.40</td>
<td>0.11</td>
<td>293</td>
</tr>
<tr>
<td>Murraya exotica*</td>
<td>2 x 2</td>
<td>2,500</td>
<td>0.15</td>
<td>0.22</td>
<td>165</td>
</tr>
<tr>
<td>Ricinus communis*</td>
<td>2 x 1</td>
<td>5,000</td>
<td>0.25</td>
<td>0.20</td>
<td>500</td>
</tr>
<tr>
<td>Acacia holosericea</td>
<td>3 x 2</td>
<td>1667</td>
<td>2.00</td>
<td>0.09</td>
<td>300</td>
</tr>
<tr>
<td>Herbaceous species</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dianella caerulea</td>
<td>1 x 0.5</td>
<td>20,000</td>
<td>0.10</td>
<td>0.19</td>
<td>380</td>
</tr>
<tr>
<td>Argemone mexicana*</td>
<td>1 x .5</td>
<td>20,000</td>
<td>0.08</td>
<td>0.18</td>
<td>540</td>
</tr>
</tbody>
</table>

* denotes two harvests per year, ** denotes three harvests per year.

It must be noted that the above classification is very much arbitrary, as there are a number of factors
that would determine the overall position of a species with respect to its ranking for biodiesel
potential. For example, Acacia holosericea: although the potential to produce oil is low, the cake can
be used in making bush tucker products which are more valued than the oil. Furthermore, this species
is very easy to grow as it can thrive well on heavily degraded soil and produces enormous quantities of
seeds. This species may be used to revegetate a barren site, but the seeds obtained from this activity
can be used as a feedstock for extracting oil, and the flour can be used in bush tucker. Likewise, many
other possibilities can be computed to include or exclude a species.
The above inferences are based on the yield potential of wild plants. As in macadamia and other wild species, it is very much possible to select high yielding genotypes that require less space and produce more seeds. Furthermore, the seeds of new selections could also contain higher proportions of the oil than what has been reported here. In this situation, the potential of the species will change.

What is most important in selecting for biodiesel feed stock is the ability of the species to grow well in the region of importance, its potential to produce sufficient quantities of seeds and the reduced variations in the oil content of the seed. As shown in Table 25, at least 10 of the selected species that occur in CQ satisfy the above mentioned conditions.

The next set of driving factors include: the ease with which the fruits can be harvested, the readiness of the fruit for use in oil extraction and the complications involved in extracting the oil and converting it to biodiesel. For example, *Elaeocarpus grandis* grows well and produces large quantities of seeds. However, its kernel content is very low and it is extremely difficult to separate the kernel from the seed. On the contrary, *Calophyllum inophyllum* grows well and also produces large quantities of seeds. Kernels of this species are much easier to separate and extract oil. Another example is *Cocos nucifera* (coconut). This species grows well in the coastal areas of CQ. It is much easier to collect fruits, separate the kernel, extract oil, and convert the oil into biodiesel for this species than for *Calophyllum*. Furthermore, the resulting cake can be sold as animal feed, and the husk can be sold to the nursery industry as potting media.

From the point of view of economics and ease of operation, amongst all the species that have been evaluated, establishment of coconuts in the region, and using various components of the palm for different purposes, will make this venture more profitable than growing any other species if a period of 10–30 years is considered. This option will not, however provide the long-term benefit of harvesting hard wood timber, unlike *Calophyllum*. If much longer term production and benefits (e.g. carbon sequestration, soil fertility) are considered, the use of *Calophyllum inophyllum*, *Pongamia pinnata*, *Aleurites moluccana* and *Santalum acuminatum* appear to become more attractive.

**Recommendations**

Detailed analysis of the variability in *Calophyllum inophyllum* for plant growth, fruit yield, kernel oil content and kernel oil composition suggests that there are gains to be made in examining provenance variations of selected species that have the potential for use as biodiesel feed stocks. Firstly, this will help identify the best seed sources for oil content; secondly this will assist in selecting plants for establishment on various locations and soil types. Third, such a study will help delineate genotype x environmental interactions so that this understanding can be made useful in crop husbandry to improve plant growth via improved agronomic practices.

Once suitable provenances are identified, the strategies required to produce sufficient planting material must be investigated to ensure that only the best genotypes are used in commercial plantations for faster growth during establishment, and sustainable production in the longer term.

The responses of selected genotypes to agronomic practices such as irrigation, fertilizers and other silvicultural practices should be studied; as such studies can markedly improve plant growth and crop yield.

Since a wide range of species have been found to contain appreciable quantities of oil, and they also differ in their growth habits and growth requirements, it is recommended that studies are undertaken to investigate whether mixed cropping or monoculture would maximise per ha production of biodiesel feedstock. For example, the feasibility of establishing mixed culture of palms, trees, palm-like plants and ground cover species (see Fig. 72) needs to be evaluated, both to maximise production and to achieve long-term sustainability.
Seeds of the potential biodiesel feed stocks are difficult to handle mechanically due to non-uniformity of size and composition. Parallel studies are therefore required to develop suitable harvesting, processing and conversion technologies to make the task of producing biodiesel economical and manageable.

It is recommended that plantations of selected genotypes be established in different locations, both to evaluate relative performances of selected species/genotypes and to use the derived seed material for long term crop improvement (elite seed orchards).
Figure 59. An hypothetical mixed cropping of biodiesel feedstock plants showing how the upper storey (coconut or Queen Palm), mid storey (*calophyllum or pongamia*), lower storey (*cordyline or petalostigma*) and ground cover species (*dianella*) can be grown.
Note: Species information was obtained from many of the following references and the websites. Likewise, the distribution maps were sourced from the websites of Australian Virtual Herbarium (AVH) (http://www.ersa.edu.au/avh/; maps with blue background) and Weeds Australia (http://www.weeds.org.au/weedident.htm; maps without blue background).


Aswathappa, N. and Marcar, N. (1990) Evaluation of 60 Australian tropical and subtropical tree species for salt tolerance. Australian Forest Research (was accepted, but not published as the journal was discontinued).


JVAP (2000) Emerging products and services from trees in lower rainfall areas. RIRDC, Canberra.


WEB RESOURCES


This report evaluates the potential of using Australian native and naturalised plant species in biodiesel production. Particular emphasis is placed on species that occur in Central Queensland (CQ) region, as significant quantities of diesel are being imported to this region, and some proportion of this could be produced locally by establishing native species on cleared land that is readily available in CQ.

More than 200 species/provenances have been evaluated for oil content, of which 20 species have been selected as having commercial potential.

This report is intended for those who are involved in decision making on alternative fuels and global warming, landcare groups and mining companies; with the view to convincing them of the potential use of native and naturalised species in biodiesel production and sustainable regional development.

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