Experimental Investigations to Demonstrate Biodiesel Potential of Beauty Leaf Tree (Calophyllum inophyllum L.)

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Abstract. Beauty Leaf Tree (BLT) is a wild Australian plant that has drawn the attention of many scientists who are searching for sustainable sources of renewable energy. This is because BLT produces about 10,000 fruits per tree, and the seeds contain up to 70% oil. Most importantly, it has the ability to grow on marginal soils in many tropical countries. The number of studies dealing with this species have escalated over the last three years, partly due to the studies carried out by the Central Queensland University (CQU). This paper summarises the results of those investigations that include testing for natural variability in growth, phenology and seed production, and developing seed collection and seed oil extraction procedures. The techniques used in converting the BLT oil into biodiesel, testing the biodiesel for engine performance and emission characteristics, and evaluating the BLT genotypes for stress tolerance are also explained. These investigations clearly demonstrate the potential of BLT to serve as the future feedstock for 2nd generation biofuel production in developed and developing tropical countries.

1. Introduction

Australia imports 85% of its diesel fuel from overseas, and this adds to the national debt. The import of fuel cannot continue forever due to depletion of natural reserves. Thus, there is a need to develop sustainable supplies of diesel within Australia. Globally also, the interest in the use of biofuels is increasing and numerous sources of renewable energies, including biofuels are being explored [1, 2, 3]. Fargione et al. [4] discusses the benefits of using 2nd generation biofuels, as this will not compete with food crops and utilizes marginal lands. Recently, Queensland Government has supported a number of pilot scale projects that deal with biorefining of new crops, and agricultural and industrial wastes [5], with the view to generating biofuels that are needed to meet the recently introduced biofuel mandate.

Why establish biodiesel plantations? and why use BLT?

Although tremendous progress has been made in biofuel production from the 1st generation feedstocks (e.g. soybean, canola, corn, palm oil), the very use of food crops for biofuel production has been fraught with ‘food vs fuel debate’. Most interestingly, this process has been demonstrated to produce more carbon debt than it could actually remediate [4]. As a result, emphasis has been placed on the use of 2nd generation biodiesel feedstocks (those derived from non-edible products or wastes). This approach is particularly preferred if the plants are established on marginal lands, as this process can also help remediate degraded soils. The 2nd generation biodiesel production process is also shown to add no carbon debt to the community [4].

Beauty Leaf Tree, also known as Calophyllum inophyllum or calophyllum or Alexandrian Laurel (Fig 1), is a wild Australian species that occurs in coastal areas of northern Australia and in many parts...
of the world [6, 7]. Although its oil has been used for medicinal purposes for centuries, this tree has not been cultivated on a large scale for commercial use [8]. The BLT shows large variations in its tree size, fruit size, fruit yield and seed oil content; 20% - 70% [9, 10, 11, 12, 13, 14]. The presence of this variability in the wild populations of BLT suggests that there are significant gains to be made in selecting superior genotypes for biodiesel production.

An understanding of its natural variability for seed oil content and its tolerance to various soil conditions is also considered critical; as such studies will help identify superior genotypes of BLT for use in commercial production. The studies on the techniques of extracting oil, converting the oil into biodiesel and testing the performance of the BLT biodiesel will help demonstrate the potential of BLT to serve as the 2nd generation biodiesel feedstock.

2. Experimental Methods

Researchers at Central Queensland University have carried out a number of studies on BLT. These include examining natural variability in the growth and phenology of BLT in Australia and Sri Lanka [9, 15], seed germination [26, 15, 12], stress tolerance [9], kernel oil extraction [16, 17, 18, 13, 20, 23, 24], conversion of BLT into biodiesel [21, 25, 31, 20], testing of BLT biodiesel for engine performance and gas emission [15, 16, 27, 28] and pyrolysis of press seed cake [29]. While detailed procedures can be obtained from the above publications, a brief description of the procedures used and the salient results are provided below.

In Australia, BLT bears fruits in two seasons (January - March and September – November). Fruits were therefore collected in different seasons and they were cracked open to separate the kernel (seeds). The fresh and dry weights of the husks and the kernels were measured. The seeds were dried slowly at 40 °C for one to two weeks prior to using them in oil extraction.

Kernel oil was extracted from dried materials either mechanically (using an oil press) or via the use of n-hexane. The oil was refined [23, 24] and converted to biodiesel. Since the BLT oil contains up to 20% free fatty acids, numerous methods of converting the oil into biodiesel were attempted [20, 24], using various reactants and catalysts [24, 20, 30, 31]. The resulting oil and the converted biodiesel were characterised to test if the BLT biodiesel will meet the ASTM and EN standards [27, 32, 34, 42]. The biodiesel that was produced as above was used in engine testing, wherein the engine performance and emission characteristics of the BLT biodiesel was compared with those of petroleum diesel.

The press cake that resulted from oil extraction process was pyrolysed using batch and auger pyrolysers at Texas A&M University, College Station, USA [17, 29].

Controlled-environment experiments were also conducted to select drought-, salt- and waterlogging tolerant genotypes of BLT [9, 33]. In some of these trials, up to 26 provenances were exposed to the above stresses for up to 12 months. Plant growth, plant water use and tissue ion concentrations are being examined, with the view to selecting provenances that show tolerance to one or more of the above stresses.

3. Experimental Results and Discussion

Selection of superior genotypes

Since beauty leaf tree is a perennial species [35], it would be very expensive and time consuming to replace it after its establishment in the field. Thus, extreme care must be taken in selecting the best performing genotypes for field scale planting. This selection process should consider both the oil content and the growth potential of BLT at a given site. Since it is advantageous to establish BLT on marginal lands, the need for identifying stress tolerant genotypes could become critically important.

Ashwath [7] has evaluated growth habitats and oil content of about c. 200 plant species and provenances. Based on this assessment, he has listed three species as having the greatest potential for biofuel production in marginal lands of tropical Australia. These species include beauty leaf tree, coconut and pongamia [37]. It is estimated that these species can produce 2000 to 4000 litres of oil per ha per year under normal conditions [7]. The above species naturally occur in coastal areas of Queensland, and they grow well in the sandy- to clay loam soils. The soils in which these species occur
are also acidic and often waterlogged, indicating that the above species have the ability to thrive on marginal soils.

CQU researchers have focused on one species, i.e., BLT and tested for its variability in kernel oil content of the trees grown in Queensland [9, 22] and in Sri Lanka [10, 11, 12]. Further testing of the genotypes that occur in Australia is currently being undertaken [9].

**Screening selected genotypes for stress tolerance**

Controlled environment experiments show that the BLT can tolerate prolonged waterlogging conditions (Fig 1; [9]). Plants that were exposed to waterlogging for 12 months maintain growth rates similar to or marginally less than that of well-watered plants. The drought exposed plants showed moderate growth, whereas the salt exposed plants were severely affected as compared to the control plants [9].

![BLT seedlings performing well in a waterlogged treatment for over a year in a glasshouse.](image)

Plant water use is also being assessed. Plants grown at field capacity consumed the most quantities of water followed by waterlogged, drought affected and salt-exposed plants. The ability of BLT to tolerate prolonged waterlogging has great implication for its cultivation in Australia and in Pacific Islands. This is because large patches of coastal areas in Australia are frequently waterlogged during rainy seasons, and these areas are not found suitable for crop production. Since BLT can tolerate prolonged waterlogging conditions, this species can be recommended for establishment on those soils. Furthermore, BLT is particularly suited for effluent irrigation, as the sites irrigated with effluent are often saturated and this will result in tree die back [36]. Since the BLT thrives very well in saturated/waterlogged conditions, BLT could serve as an excellent species for biodiesel production from effluent irrigated projects.

The ability of BLT to tolerate saturated soil conditions, its potential to use large quantities of water, and its inherent feature to produce oil-rich seeds makes BLT the sought after species for use in effluent irrigation. The use of waste lands, the use of wastewater which otherwise flows into the ocean, and the use of the non-edible oil for biodiesel production, all make BLT the best candidate for 2nd generation biofuel production.

The BLT can be co-cultivated in a multistorey system, with coconut as the tall emerging species, and BLT and pongamia as the midstorey species [Fig 2]. Other species such as cordyline (which also has biodiesel potential) could be grown as an understory species [7]. The use of pongamia can help fix atmospheric nitrogen, thus ensuring long-term sustainability of biodiesel plantations. If the multiple cropping design is chosen, then the available space will be well utilized and the establishment, maintenance and harvesting processes can be streamlined. Such an integration can lead to more efficient means of producing biofuels.
Figure 2. Beauty leaf tree co-occurring with coconut.

Fruit collection and kernel processing

In most of the studies that are listed in this paper, BLT fruits were collected manually from wild plants. Fruit harvesting can however be mechanized as in macadamia or pecan nut industries. The fruits were cracked-open manually [19, 41, 16, 18]. Again, this process can be mechanised using a technology similar to the one used in macadamia industry. Seed drying also needs optimizing, as the exposure of the whole seed to higher temperature results in exudation of resin and burning of the kernel in the centre. Breaking the kernels into small pieces, prior to drying, and drying at lower temperature for longer periods could alleviate the above problem.

Oil extraction and refining

The BLT oil content varies significantly between trees, seasons and the locations. These variations can range from 20% to 70% [9, 17]. The variations that are associated with the collection (mature fruits vs immature fruits, dropped vs intact fruits), seed drying (40 °C , 70 °C or 105 °C) and the method of extraction (oil press vs solvent extraction [18, 9] play a very important role in estimating BLT kernel oil content. Research is therefore needed to optimise these processes to suit the requirements of the biofuel processing factory.

The mechanically extracted oils contain fine residues of press cake, water, rosin and other impurities. Some of these, and particularly the water and the free fatty acids must be reduced before the oil can be converted into biodiesel. Oil refining [44] appears to overcome some of the problems associated with transformation. However, this process may result in the loss of oil (up to 25%). The refining process can also add production cost, and introduce added chemicals into the oil.

Conversion of BLT oil to biodiesel

In most feedstocks, biodiesel is produced using alkali-catalysed transesterification. However, this technology is not suitable for BLT, as it contains high proportion of free fatty acids [20]. Two-stage acid catalysed esterification is found effective for BLT oil [40]. This conversion process yielded 78% to 93% biodiesel when unrefined and refined BLT oil was used respectively [44]. Four-stage transesterification was also tested using unrefined BLT oil. This process yielded 88% biodiesel compared to 77% in alkali-catalysed transesterification [20].

Other methods of converting BLT oil into biofuels, such as hydrogenation to produce hydrogenated vegetable oil (HVO), Fisher-Tropsch conversion, supercritical method, enzymatic conversion, etc are recommended to find the most economical and reproducible technique of transesterifying BLT oil.

BLT Biodiesel composition and its properties

The BLT biodiesel consists primarily of five fatty acid methyl esters. They are palmitic acid methyl ester (15%), stearic acid methyl ester (15%), linoleic acid methyl ester (25%) and Oleic acid methyl ester (40%) and other esters (5%). Relative proportion of these methyl esters vary from one source to the other, as well as the techniques used in converting the BLT oil into biodiesel [15, 16].

Biodiesel testing for engine performance and emission characteristics

The BLT biodiesel was tested for engine performance at different scales of operation. The test performed by Hathurusingha [15] showed slightly reduced power with BLT biodiesel as compared to
petrodiesel. Subsequent to this test, the BLT biodiesel was used in an autorikshaw in Sri Lanka [35]. Bhuiya et al. [16, 27] used a dynamometer to test several blends of BLT biodiesel for engine performance and emission. They found that the 5% blend of BLT biodiesel produced as much as 97.3% of torque as compared to the petrodiesel. The B5 also reduced carbon monoxide emission by 5.1% at 50% load. Azad et al. [34] and Bhuiya et al. [42] have evaluated engine performance of mixtures of BLT and poppy oil biodiesel, and BLT and jojoba oil biodiesel. All these tests unequivocally suggest that the BLT biodiesel can be successfully used in the existing diesel engines without any modifications.

Potential use of BLT in small and large-scale biofuel production and identification of potential sites for establishing BLT plantations

Because the BLT and the coconut co-occur on course-textured soils that are often acidic (3.3 to 5.5), both these species may be cultivated in a mixed plantation (Fig 2). Pongamia is another biodiesel feedstock and this could also be grown with BLT [37] in selected sites, as this can fix atmospheric nitrogen. Establishment of mixed species will result in the production of more fuel per hectare, and require less energy and chemical input per production in terms of net GJ of energy produced per hectare of land used [4, 43].

Tropical Australia has vast area of land that has been cleared and used for grazing. Part of this landscape can be used to establish BLT plantations. Identification of potential growing regions based on climatic requirements of BLT for its seed production, is needed to convince the farmers and biofuel entrepreneurs to use BLT in large scale plantings. Bioclimatic simulation has been carried out for other species [45, 46, 47]. Similar studies in BLT will help identify suitable sites for planting BLT.

A preliminary bioclimatic simulation showed that the BLT can be grown over a large are in tropical Australia, from Rockhampton through Townsville, Cairns, Cook town, Darwin and finally to Broome. The BLT planting could occur inlands up to 100 km form the coast.

The BLT can offer many benefits to rural communities. Ideally, farmers can set aside a portion of their land (preferably marginal land) for BLT production, and claim carbon credits, if such an activity is supported by the government. Establishment of BLT on previously cleared land could help re-green the land, reduce soil erosion and thus protecting the pristine environments such as the Great Barrier Reef from nutrient loading. The oil cake from biodiesel production, and the biochar and bioliquor that result from pyrolysis of oil cake [29] can also be used to improve soil health and fertility. At the conclusion of biofuel production, the BLT timber can be used as hardwood timber- thus serving as a dormant income source for growers.

On a larger scale, BLT cultivation and biodiesel production could create new jobs and this could lead to retention of youth in rural areas. Most importantly, large-scale production of biodiesel could reverse land degradation, while also providing longer-term solution to fuel needs of the country. Queensland, in particular, clears up to 400,000 ha of land every year, and some of this cleared and unused land could be made use in biodiesel production.

Larger entrepreneurs that are keen to produce substantial quantities of biofuel (eg Northern Oil Refineries in Gladstone) could encourage farmers to establish BLT plantations in selected locations. The BLT fruits can be processed on the farm to produce biocrude, which can then be transported, and upgraded to different types of biofuels (Biojet, biodiesel, etc) at a centralised processing plant, such as the one located in Gladstone. This scheme will help put back part of the vegetation that was removed from the landscape. Such technological investment can also help solve both social and environmental issues of rural communities.

4. Conclusion

The CQU research has examined provenance variation in BLT with the view to choosing the best genotypes for commercial cultivation. The research has also optimised methods for oil extraction and conversion. The BLT biodiesel has been characterised and tested for engine performance. Results of these studies clearly demonstrate that BLT can serve as an excellent 2nd generation biodiesel feedstock while also assisting in land remediation and generating sustainable income to rural communities.
The use of BLT has significant environmental and economic advantages, as it addresses a highly critical problem of managing our use of the Earth’s resources. Firstly, it aims at utilizing marginal lands that are otherwise not utilized. Additionally, it proposes to use a species that has wide adaptability, and produces abundant quantities of oil seeds that are not fit for human consumption. The use of BLT for biofuel production will also exhibit an alternative way of re-greening Australia’s landscape.

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