An assessment of biodiesel feedstock conversion efficiency: a case study of decentralised biofuel production program in rural India

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Abstract: In response to a national ambitious biofuel policy, the Indian state of Karnataka launched a feedstock development program on the principles of decentralisation, sustainability, and multiple fuel sources. A network of farmers oilseed associations are being formed in order to encourage farmers to grow, pool and process a large number of small-scale oilseed productions. Success of such program depends on the conversion efficiencies of the feedstock at multiple stages and value added by-products. This study focuses on one of the program crops, *Simarouba glauca*, as a test case. The conversion efficiency of the village-level, decentralised production model was assessed and compared with the theoretical biodiesel production efficiency. The study indicated that the field-level feedstock conversion efficiency was less than that of the lab-scale set up. However, the fuel qualities of the *Simarouba glauca* biodiesel were found to be of standards required for fuel designation. The study shows that there is a significant potential for improving the field-level feedstock conversion efficiency through technical improvements and best practices in oilseed collection, curing and conversion. The study offers a few programmatic and policy suggestions for such improvements.

Keywords: transesterification; India; technical efficiency; biodiesel; non-edible oilseed; *Simarouba glauca*.

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1 Introduction

Biodiesel production and use has been gaining popularity in the last two decades (Singh and Singh, 2010). Biodiesel is considered a secondary first generation biofuel because of its feedstock and form of processing. Different natural renewable resources such as raw vegetable oils (Nigam and Singh, 2011; Akoh et al., 2007), processed resources, and waste resources are used for making biodiesel. Vegetable feedstock oils can be obtained from a variety of renewable resources such as plant and animal stocks (Akoh et al., 2007; Marchetti et al., 2008).

Being the second most populous country in the world, the fuel demand of India is growing fast. The country has embarked on an ambitious policy for promoting biofuel production. The 2009 national biofuel policy of the Government of India sets targets of 20% mixture of biofuels for gasoline and diesel by 2017 (Government of India, 2009). However, the biofuel research and technology development that is necessary to support this national program is in its infancy.
In the past, researchers have demonstrated that raw vegetable oils can also serve directly as an alternative to conventional fuels in diesel engines (Goering et al., 1982; Bagby, 1987). For example, one researcher ran a tractor on sunflower seed oil for 1,000 hours with an 8% power loss (Bruwer et al., 1981), and another researcher demonstrated that rapeseed oil had similar energy output to diesel (Schoedder, 1981). However, certain technical difficulties still exist. Some studies documented problems associated with the use of vegetable oil such as heavy wax and gum deposits in diesel engines and carbon build up in the combustion chamber with sunflower oil (Tahir et al., 1982; Bacon et al., 1981). Further, engines run on rapeseed oil reportedly had some difficulties on account of carbon deposits on piston rings, valves and injectors after 100 hours (Schoedder, 1981).

However, research continues to make vegetable oils usable through a variety of technical means. For instance, it is shown that the carbon deposits can be lowered if the oil is heated prior to combustion, and that the carbon deposits are a function of oil composition such as high viscosity (Reid et al., 1989). Blending vegetable oil with conventional diesel fuel at different proportions can minimise deposits and extend the life of the engine (Engelman et al., 1978; Quick, 1980). Such research and technology efforts continue to unravel the potential that non-edible vegetable oils hold as a renewable energy resource.

One of the challenges that a renewable biodiesel program faces especially in a developing country is the steady and sufficient supply of feedstock. The feedstock supply has to come from a large number of large-, medium- and small-scale farmers who are generally distributed across a wide region. The Indian state of Karnataka has recognised this challenge and has embarked on a multi-species and farmer-centred approach in order to take advantage of different synergistic potential in the production of biofuels (KSBDB, 2009). The small scale or farmer centred production of feedstock and biofuel is found to have the potential to improve agriculture markets, enhance agriculture productivity, and reduce atmospheric pollution in rural areas (Sarantopoulos et al., 2009). If done correctly on-farm production of biofuels takes advantage of the synergistic potential of several aspects of agriculture in a manner that can improve the ecological integrity of the system. Farms can take advantage of the synergistic potential through the cycling of nutrients and energy using crops grown on farm to meet on farm demands (Ikerd, 2006). Furthermore, small scale biofuel production models have been particularly appropriate in places where petroleum fuels are expensive and hard to find such as developing countries (Demirbas and Demirbas, 2007).

The long-term success of a decentralised, small scale biofuel production program however heavily depends on the efficiencies of feedstock collection and conversion at multiple stages in the rural area: from oilseed to oil, oil to biodiesel, and biodiesel to energy throughput (Singh and Singh, 2010). The Karnataka State Biofuel Development Board (KSBDB), a state agency, and the University of Agricultural Sciences (UAS), Bangalore, have collaborated to encourage farmers to organise into a large network of cooperative oilseeds associations, along the model of India’s popular milk cooperatives (KSBDB, 2009). The network now consists of 32 district level oil seed collection centres and 465 village-level oilseeds associations state-wide. Twenty-three of the oilseeds associations have their own oil expellers for value addition. Each village oilseed association could have 25–50 members and a biofuel crop area of 5–20 hectares. Most of
the times non-edible tree crops (e.g., *Simarouba glauca*, jathropa, pongamia, and neem) are grown on both private lands (mostly along fence lines) and unused public lands.

The members of the associations that do not have their own oil expellers pool their small-scale seed productions and send the same to the district level centres for conversion into biodiesel. Previous research points out the benefits of small scale biofuel production are contingent on the cost of the production and on the ability to maintain mechanical efficiency and durability during use (Fore et al., 2011). Additionally, small scale production is reliant on the implementation of testing biofuels for quality control to protect equipment from mechanical detriment.

The main purpose of this paper is to determine the technical efficiency of the feedstock preparation and conversion process currently being adapted under the KSBDB-promoted decentralised community-based program. This study focuses on *Simarouba glauca* or paradise tree as a test case as this is currently the most popular of all non-edible oilseed crops being promoted by KSBDB and UAS. This crop has multi-purpose usage in the rural context. The efficiency of the field-level feedstock-oil conversion units is compared to the theoretical conversion efficiency obtained in a laboratory experimental setup. The properties of the oil and the biodiesel produced are tested using and compared to the American Society of Testing and Materials (ASTM) standards and European standards to determine quality of the biodiesel. Further, we test key fuel properties, including viscosity, density, acid value, calorific value (CV), flash point, pour point, and cloud point. Finally, we offer policy recommendations to improve the technical efficiency of the program.

2  Methods

Under the program being promoted by the KSBDB and UAS, farmers grow the oilseeds and prepare the seeds for oil expelling individually. Seeds are then pooled at the village or district collection centres and converted to vegetable oil before it is transported to large collection centres. As the program evolves into a larger scale, the goal is to have a nodal biodiesel manufacturing plant that receives vegetable oil from multiple village cooperatives, a model similar to the milk cooperative network in the country. Such a model allows all the by-products, such as seed cake to be used at the community level.

We first visited a few village centres to identify and observe the actual process of converting the *Simarouba glauca* seeds into biodiesel in the rural context. Then, we tried to mimic each step along the seed-to-diesel conversion process. We used 200 kg of seeds collected from the university experiment station’s plantations. The entire seed was sun dried for several days prior to storage and stored for approximately three months prior to the experiment. Since several environmental and management factors could influence the final technical efficiency of oil conversion, it is important to understand the process underlying each step along the seed-to-oil chain, which is explained below.

2.1  Seed decortication

Decortication is an essential step prior to milling and extracting the oil from the kernel or seeds. While there is extensive research on the decortication of various edible feedstock there is still little research done on the decortication of alternative feedstock like...
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*Simarouba glauca* (Pradhan et al., 2010). Farmers and researchers in the study area still use a decorticator similar to the machine used for ground nut. For this research, 200 kg of the whole seeds of *Simarouba glauca* were input into the decorticator in 10 kg increments; the time it took to decorticate each increment was recorded along with the weight of seeds being separated and the shells. The seeds that failed to separate were weighed with the shells. The average recovery of seed kernels compared to shells or husk for each increment was calculated to determine the efficiency of the process. The following statistical regression was estimated to determine if the time the mechanical decorticator was run had any effect on the efficiency of the decortication process.

\[ D = a + bT + \epsilon \]

where \( D \) is the percent of kernels recovered from decortication; \( T \) is the duration of decortication; \( a \) and \( b \) are the regression coefficients; \( \epsilon \) is the random error.

### 2.2 Oil expelling and extraction

Expression refers to the process of pressing the liquid out of liquid containing solids mechanically where extraction refers to the process of separating a liquid-solid system (Matthaus and Bruhl, 2001). Mechanical expression of seed oils using a screw press is said to be the oldest and most popular method of expelling oil from seeds in the world (Pradhan et al., 2011). While solvent extraction has proved to be more efficient, the simplicity and safety aspects of mechanical expelling have made it the more advantageous process. Further, Pradhan et al. (2011) finds that solvent extraction adds chemicals contaminating the protein rich cake that can be used or sold to increase the efficiency of the production model.

The oil expeller used in the study was produced by Sardar Engineering Company and was expected to be widely used at the rural oilseed collection centres throughout the state. The mix of seed husk and kernels from decortication were input into the expeller in 12 different increments. Data were collected with methods adapted from Pradhan et al. (2011) where the mass of the cake \( (M_{cake}) \) is multiplied by the oil content of the cake \( (O_{cake}) \), and then is divided by the recorded mass of the sample \( (M_{sample}) \), multiplied by the initial oil content of the seed \( (O_{seed}) \) to obtain a value of oil recovery \( (OR) \). The result from the above calculation is then is subtracted from 1 and multiplied by 100 to get a percentage (Pradhan et al., 2011).

\[ OR = \left(1 - \frac{M_{cake} \cdot O_{cake}}{M_{sample} \cdot O_{seed}}\right) \times 100 \]

Further, the initial oil content of the seeds was determined using chemical extraction and the mechanical data were compared statistically using an independent sample \( t \)-test to determine and compare their efficiency (Green and Salkind, 2010). To determine the theoretical maximum oil yield from the seed, we used the Soxhlet method of chemical extraction that involved the extraction of oil from the solid material by repeated washing with organic solvent, diethyl ether, followed by gravimetric determination (Matthaus and Bruhl, 2001).
2.3 Oil transesterification

The seed oil that was extracted in the above process was then converted into biodiesel using simple transesterification. On the basis of the acid-value we chose to do a one-stage transesterification. For lack of resources and time, we were unable to perform a two-stage transesterification that involved an acid esterification pre-treatment (Sadasivam and Manickam, 1996). The transesterification process was carried out in 1 L batches at atmospheric pressure in a closed vessel at a constant temperature of 60°C (Knothe et al., 2005). Once, the oil reached a constant temperature in the vessel, a mixture of methanol and sodium hydroxide was added. The amount of sodium hydroxide was determined using the acid value and the following equation:

\[
\text{Amount catalyst} = 3.5 \text{ g sodium hydroxide} + A
\]

where A is the acid number of the oil.

The oil, methanol, and sodium hydroxide were mixed continuously for 1–1.25 h (Knothe et al., 2005). The liquid from the vessel is placed in a separating funnel where the denser glycerine sinks down the bottom where it is easily separated. Following separation the biodiesel was washed once with 1,000 ml of hot water acidified with organic acids, and then several washes of just hot water. Finally, the biodiesel was heated to a temperature of 120°C to remove the moisture from the mixture (Sadasivam and Manickam, 1996).

2.4 Identification of Simarouba glauca oil and biodiesel fuel properties

Testing procedures for the identification of the fuel properties of Simarouba glauca oil and biodiesel were adapted from the UAS model and Sadasivam and Manickams’ Biochemical methods (Sadasivam and Manickam, 1996). The testing procedures used by UAS are comparable but not fully up to date with the testing procedures required for certification under ASTM standards, Indian standards, or European standards (National Biodiesel Board, 2009). Fuel properties tested for include acid value, viscosity, iodine value, density, CV, flash point, pour point, and ash contents (Sadasivam and Manickam, 1996).

Determining the acid value was accomplished by titrating the sample against potassium hydroxide (KOH) and a phenolphthalein indicator (Sadasivam and Manickam, 1996). The acid number is the milligram of KOH required to neutralise the free fatty acids present in 1 gram of sample. The free fatty acid content is expressed as oleic acid equivalent.

\[
A = \frac{R \cdot N_{\text{KOH}} \cdot 56.1}{W}
\]

where \(A\) is the acid value in mg; \(R\) is the titrate value of KOH (ml); \(N_{\text{KOH}}\) is the normality of KOH; and \(W\) is the weight of the biodiesel sample (gm).

The free fatty acid (\(F\)) in percent is calculated as oleic acid using the equation:

\[
F = \frac{A}{2}
\]
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The iodine number of the oil or biodiesel \((I)\) is a measure of the degree of unsaturation present in the sample. It is expressed as the grams of iodine absorbed by 100 grams of sample, where the excess iodine remaining is estimated by titrating against sodium thiosulphate.

\[
I = \frac{(V_1 - V_2) \cdot N \cdot 126.9 \cdot 100}{W \cdot 100}
\]

where \(V_1\) is the volume of sodium thiosulphate in (ml) used for blank; \(V_2\) is volume of sodium thiosulphate used for sample; \(N\) is normality of sodium thiosulphate.

When the triglycerides in the sample are heated with KOH, they are saponified releasing fatty acid and glycerol. The fatty acid neutralises the KOH and a titration with hydrochloric acid (HCl) is used determine the amount of alkali used for saponification \((SV)\) (Sadasivam and Manickam, 1996).

\[
SV = \frac{(V_1 - V_2) \cdot N_{HCl} \cdot 56.1}{W}
\]

where \(V_1\) is the volume of HCl in ml used for blank; \(V_2\) is the volume of HCl used for sample; \(N_{HCl}\) is the normality of HCl.

The viscosity of the oil and biodiesel was determined using a Redwood No 1 viscometer. The apparatus determines the viscosity of the sample by releasing it through a standard orifice into another standard collecting jar at a specific temperature. The viscosity \((V)\) is expressed as the time of flow in seconds \((R)\) (Sadasivam and Manickam, 1996).

\[
V = \frac{0.260R - 179}{R}, \text{ when } 34 < R < 100
\]

\[
V = \frac{0.247 - 50}{R}, \text{ when } R > 100
\]

A Macro Scientific Works bomb calorimeter was used to determine \(CV\). A bomb calorimeter is commonly used device to determine the heating or \(CV\) of a solid or liquid fuel sample at a constant volume. It basically works by burning a sample of the fuel that transfers its heat into a known mass of water. Using the weight of the sample in grams \((W)\) burned and the temperature rise of the water \((T)\), the \(CV\) can be calculated. The \(CV\) here represents the gross heat of combustion per unit mass of a sample (Sadasivam and Manickam, 1996)

\[
CV = \frac{(G \cdot C \cdot T) - E}{W}
\]

where \(G\) is the mass of water; \(C\) is the specific heat of water; \(E\) is the calories of heat combustion required for the fuse and wire to burn.

Cloud point and pour point for the biodiesel was determined using a UAS custom made apparatus that is combined with Indian standard specific thermometers and volumetric containers. The sample is put into a test jar that is protected by a jacket and inserted into several containers with decreasing temperature. The cloud point and pour point are observed and recorded visually.
Density was determined using a hydrometer of Indian standard similarly to the low temperature thermometers used above. A sample of the oil is placed in a volumetric container. The hydrometer is immersed in the sample and gives a density reading. To determine the flash point of the biodiesel a Pensky Martens flash point apparatus was used. It has a smooth operating cover mechanism that slides a shutter open and applies a test flame to the sample at the turn of a knob. The flash point is identified visually and the temperature of the oil is recorded.

2.5 Data analysis

All data were analysed using IBM SPSS Statistics 19. An independent sample t-test was applied to the chemical extraction procedure data and the mechanical extraction data to test the variability and difference in means. A linear regression was used to test the relationship between time and different output variables to see how much the time variable affects the output of a process (Green and Salkind, 2010). For all the fuel properties test were done in triplicate and results are the mean of the three test.

3 Result

3.1 Seed decortication

Out of the 200 kg of seed processed in the decorticator there was 91.89 kg of useable material for expelling. There was 68.82 kg of seed husk and whole seeds that failed to separate in the machine. The total time the decorticator was run was 676 minutes. The average yield percentage of the process was estimated to be,

\[
\frac{91.89 \text{ kg}}{200 \text{ kg}} \times 100 = 45.95\% \quad \text{and} \quad \frac{91.89 \text{ kg}}{679 \text{ minutes}} = 0.136 \text{ kg/minute}
\]

The mixture of mostly husk and whole seed were manually sifted to remove whole seeds. The husks were used as mulch.

A linear regression analysis was conducted to evaluate if the amount of time (T) the decorticator was operational in each batch had a relationship on the amount of kernel and seeds that were separated (D). The study hypothesis was that the two are linearly related in that as overall time increases so does the amount of kernel and seeds that are separated. The estimated regression equation is:

\[
D = 0.015 T + 4.101 \quad R^2 = 0.048, n = 20
\]

\[
(SE = 0.016) \quad (SE = 0.544)
\]

The slope parameter was not statistically significant at 5% level, meaning that the amount of kernels separated was not significantly related to the amount of time the machine was run.
3.2 Oil expelling and extraction

Out of the 91.89 kg of seed kernel/husk mixture obtained from decortication, an amount of 88 kg was input into the expeller for expelling. About 3 kg were lost during the transfer of seed kernel from one process to the other, probably due to the moisture loss. The process of expelling yielded 9.223 kg of oil in 190 minutes. The average yield in percent of the oil expeller was \( \frac{9.223}{88} \times 100 = 10.49\% \) at 0.46 kg/min. After expelling there was about 59.42 kg of seed cake, a value added by-product that could be used for fertilisers, manures and pesticides, and 19.357 kg of residue that was separated from the oil by letting it settle and filtering.

Using the Soxtherm method of extraction it was found that the seed kernel plus husk mixture used for expelling had an oil percentage of 29.74%. The left over cake and residue were also tested using the Soxtherm method of extraction and their oil percentages were 10.49% and 69.06%, respectively. Lastly, the chemical extraction method was used to determine the percent of oil for the seed kernel (60.25%) by itself and the full seed (14.87%).

An independent-samples t-test was conducted to evaluate if the mechanical expelling of the *Simarouba glauca* oil using the field-level model expeller was comparable to the Soxtherm chemical extraction (Pradhan et al., 2011; Matthaus and Bruhl, 2001). The test was significant (\( p < 0.001 \)). The mechanical expelling (\( M = 7.333\%, \ SD = 2.109 \)) had a lower mean percent OR than the chemical extraction (\( M = 29.736\%, \ SD = 3.030 \)) as expected, but the mean for the mechanical expeller was lower than anticipated.

Equal variances was assumed because the Levene’s test for equality was not significant (\( p = 0.18 \)) meaning the assumption of equality of variances was not violated. The 95% confidence interval for the difference in means was narrow ranging from −24.629 to −20.178 (Green and Salkind, 2010). Figure 1 shows the difference between the average distributions of the OR of the mechanical expeller and the chemical extraction in the lab.

**Figure 1** The average oil recovery for both the mechanical expelling method and Soxtherm chemical extraction method (see online version for colours)
3.3 Oil transesterification

From the 9.223 kg mechanically expelled oil, 9 L of oil was separated leaving about 100 ml of simarouba oil as excess from the whole process. The oil was converted into biodiesel in nine 1L batches and 8.122 L of biodiesel was produced. The average yield percentage of transesterification was \((8.122/9.223) \times 100 = 90.24\%\) (Table 1). There was 2.712 L of by-product, which was mostly glycerine (another value added product) separated from the oil.

Table 1: Data collected from the transesterification

<table>
<thead>
<tr>
<th>Batch</th>
<th>Oil (ml)</th>
<th>Methanol + Catalyst (ml)</th>
<th>Biodiesel recovered (ml)</th>
<th>Un-reacted material</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,000</td>
<td>250</td>
<td>901</td>
<td>305</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>1,000</td>
<td>250</td>
<td>898</td>
<td>300</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>1,000</td>
<td>250</td>
<td>900</td>
<td>298</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>1,000</td>
<td>250</td>
<td>910</td>
<td>295</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>1,000</td>
<td>250</td>
<td>911</td>
<td>290</td>
<td>60</td>
</tr>
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<td>6</td>
<td>1,000</td>
<td>250</td>
<td>305</td>
<td>302</td>
<td>75</td>
</tr>
<tr>
<td>7</td>
<td>1,000</td>
<td>250</td>
<td>895</td>
<td>310</td>
<td>75</td>
</tr>
<tr>
<td>8</td>
<td>1,000</td>
<td>250</td>
<td>301</td>
<td>300</td>
<td>75</td>
</tr>
<tr>
<td>9</td>
<td>1,000</td>
<td>250</td>
<td>301</td>
<td>312</td>
<td>75</td>
</tr>
<tr>
<td>Mean</td>
<td>1,000</td>
<td>250</td>
<td>902.44</td>
<td>301.33</td>
<td>66.67</td>
</tr>
</tbody>
</table>

3.4 Fuel properties

Table 2 shows the fuel properties obtained Simarouba glauca biodiesel and oil according to the procedures and apparatus available at UAS. All fuel properties were determined in triplicate and the result shown is the average of the three trials.

Table 2: Fuel properties obtained for Simarouba glauca biodiesel and oil in the study

<table>
<thead>
<tr>
<th>Properties</th>
<th>S. glauca biodiesel</th>
<th>S. glauca oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid value (mg KOH/g)</td>
<td>0.24905</td>
<td>2.2465</td>
</tr>
<tr>
<td>Viscosity at 4°C (mm²/s)</td>
<td>12.609</td>
<td>60.535</td>
</tr>
<tr>
<td>Calorification (MJ/kg)</td>
<td>32,143</td>
<td></td>
</tr>
<tr>
<td>Saponification</td>
<td>179.561</td>
<td>185.9317</td>
</tr>
<tr>
<td>Density</td>
<td>867</td>
<td></td>
</tr>
<tr>
<td>Cloud point (Celsius)</td>
<td>18</td>
<td>Room temperature</td>
</tr>
<tr>
<td>Pour point (Celsius)</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Iodine number</td>
<td>56.03</td>
<td>54.28</td>
</tr>
<tr>
<td>Flash point (Celsius)</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>Ash content (%)</td>
<td>0.00485</td>
<td></td>
</tr>
</tbody>
</table>
4 Discussion

4.1 Feedstock-to-biodiesel conversion efficiency

The community level biodiesel production model exhibited some efficient aspect and some not so efficient ones (see Figure 2). Of the 200 kg of *Simarouba glauca* that was obtained in the beginning of the research 8.122 L of usable biodiesel was obtained. 1 L of biodiesel roughly weighed 1 kg. This amounts to seed-to-oil conversion of 

\[
\frac{8.122}{200} \times 100 = 4.06\%.
\]

While this OR is low, a small scale community production model is able to take advantage of the by-products such as seed husks, oil cake, and sludge for local uses, which would not be possible in a large scale biodiesel production operation.

![Figure 2](see online version for colours)

The process of seed decortication did not seem efficient. Out of the 200 kg of seed that were processed only 91.89 kg or 45.95% that was usable for oil extraction. The husk was used as mulch, which was beneficial to the community. One observation was that the machine was not being run long enough for all the seeds to move through, but the data indicated that the amount of useable seeds that were output from the decorticator had no relation with the amount of time that the machine was operated. Some of the missing weight can be attributed to these whole seeds that were not separated or to husks that were ground into a thin powder.
Pradhan et al. (2010) found that in the case of *Jatropha curcas* decortication yielded higher amounts of kernel as the moisture content decreased. They also found that as the moisture content increased, there was a decrease in the amount of broken seed and dust. However, we were unable to record the moisture content of the seeds in our research.

The process of oil expelling yielded 9.233 kg of oil from the initial 91.89 kg of seed kernels and husk that was input into the expeller, which amounted to 10.05%. This efficiency rate is almost one-third of the OR rate of 29.74% from the Soxtherm chemical solvent extraction method. This low recovery percentage of the mechanical process might be attributed to oil being left in the oil residue and seed cake. There was 59.42 kg of seed cake that had an average oil content of 10.49%. Additionally, there was 19.357 kg of residue that had an average oil content of 69.06%. That meant that there was an estimated total of 19.6 kg of oil trapped just in the cake (6.23 kg) and the residue (13.37 kg).

The percent recovery was very low compared to other published expelling studies that reported a recovery rate between 86%–92% of oil from oilseeds (Pradhan et al., 2011). Studies have shown that adjusting certain parameters of the expeller such as internal pressure of the screw press can result in a decrease in the amount of oil left in the cake increasing the efficiency of OR (Pradhan et al., 2011). Also, further pretreatment of the oilseed for example cleaning, cooking, and drying have been said to enhance OR as well. From our visual observation it seemed that applying a filter between the oil collection and the oil expeller could also have minimised the amount of residue left in the oil.

At UAS the *Simarouba glauca* cake was being used to amend fields directly as a green manure or mixed in with organic composting and then applied to fields. While there are not many studies on the cake of *Simarouba glauca*, the past research suggests that it has a high protein content of about 48% (Govindaraju et al., 2009). The study also suggests that it is a rich source of protein for livestock meal with 92% solubility, in vitro protein digestibility of 88%, and amino acid-based computed nutritional indices (Govindaraju et al., 2009). However, *Simarouba glauca* cake requires detoxification before it could be utilised in feed/food formulas.

The last phase of the community level production model that was examined was the transesterification process. The transesterification process seemed the most efficient of all the processes. A total of 9.223 Kgs of vegetable oil yielded 8.122 L biodiesel. Because the acid value (2.25) was a little high, an acid catalyst esterification pre-treatment process could have been beneficial to the overall recovery of biodiesel (FAME) from the *Simarouba glauca* oil, but it would have required a lot more chemical materials (Singh and Singh, 2010). The UAS does the two-step process on oil that has an acid value greater than two (Sadasivam and Manickam, 1996). However, the one step transesterification yielded 8.122 L biodiesel from the 9 L of *Simarouba glauca* oil input or 90.24% OR. The transesterification process seemed pretty efficient in comparison to the other parts of the production process. In addition, the 2.712 L of un-reacted material that was mostly glycerol was added to collection of glycerol for the production of soap and if further purified could be sold for industrial processes.

### 4.2 *Simarouba glauca* fuel quality

The properties of *Simarouba glauca* oil and biodiesel were compared with ASTM D6751 and European Standards EN 14214, which are the two of the most popular quality standards of biodiesel throughout the world (Gui et al., 2008; National Biodiesel Board, 2009) (see Table 3). The *Simarouba glauca* biodiesel fuel properties are also compared to
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the fuel properties of popular edible and non-edible feedstock (Gui et al., 2008). The Simarouba glauca biodiesel produced at the study site met some important quality standards but failed to meet others. The unaltered Simarouba glauca oil did not meet any of the fuel standards for diesel fuels. Quality testing of biodiesel is one of the larger impediments to the success of small scale biofuel production models (Fore et al., 2011). By using cheaper low-tech fuel property testing procedures, the UAS model is able to determine some quality standards of the fuel they are producing and they can implement more quality control for the fuel they are creating in the rural communities.

### Table 3

<table>
<thead>
<tr>
<th>Properties</th>
<th>SG B100</th>
<th>SG oil</th>
<th>Jatropha B100</th>
<th>Rubber seed</th>
<th>Palm</th>
<th>Soybean</th>
<th>Diesel</th>
<th>ASTM D6751-02</th>
<th>EN 14214</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid value (mg KOH/g)</td>
<td>0.24905</td>
<td>2.2465</td>
<td>0.4</td>
<td>0.118</td>
<td>0.08</td>
<td></td>
<td></td>
<td>&lt; 0.8</td>
<td>&lt; 0.50</td>
</tr>
<tr>
<td>Viscosity at 4°C (mm²/s)</td>
<td>12.609</td>
<td>60.535</td>
<td>4.8</td>
<td>5.81</td>
<td>4.42</td>
<td>4.08</td>
<td>2.6</td>
<td>1.9–6.0</td>
<td>3.5–5.0</td>
</tr>
<tr>
<td>Calorification (MJ/kg)</td>
<td>32,143</td>
<td>39,230</td>
<td>36,500</td>
<td>39,760</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saponification</td>
<td>179.561</td>
<td>185.9317</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>867</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>860–900</td>
</tr>
<tr>
<td>Cloud point (Celsius)</td>
<td>18</td>
<td>Room temperature</td>
<td>4</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pour point (Celsius)</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>–20</td>
</tr>
<tr>
<td>Iodine number</td>
<td>56.03</td>
<td>54.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flash point (Celsius)</td>
<td>160</td>
<td>135</td>
<td>130</td>
<td>182</td>
<td>69</td>
<td>68</td>
<td>&gt; 130</td>
<td>&gt; 120</td>
<td></td>
</tr>
<tr>
<td>Ash content (%)</td>
<td>0.00485</td>
<td>0.012</td>
<td>0.02</td>
<td>0.01</td>
<td></td>
<td>&lt; 0.02</td>
<td></td>
<td>&lt; 0.02</td>
<td></td>
</tr>
</tbody>
</table>

**Source:** Gui et al. (2008) and National Biodiesel Board (2009)

The acid value of the Simarouba glauca biodiesel was 0.24905 mg KOH/g and 2.25 mg KOH/g for the oil. The ASTM and European Standards for acid value are < 0.8 mg KOH/g and < 0.50 mg KOH/g, respectively (National Biodiesel Board, 2009) (see Table 3 for comparison). The acid value for the Simarouba glauca biodiesel was less than the acid value for Jatropha curcas, but not less than other popular feedstock such as rubber seed and palm (Gui et al., 2008). Therefore, the acid value was of an acceptable quality for the biodiesel produced at the study site. The viscosity (12.609 mm²/s at 40 degrees Celsius) for the Simarouba glauca biodiesel did not fall in the range of the accepted viscosity for the European standard (3.5–5.0 mm²/s at 40 degrees Celsius) or the ASTM standard (1.9–6.0 mm²/s at 40 degrees Celsius) (National Biodiesel Board, 2009). In fact it was way above the standard and all the other biodiesels that it was compared with. Meeting the viscosity standard is an important consideration in biofuel selection because viscosity is one of the major contributing causes of carbon deposits in diesel engines. Viscosity affects the atomisation and injection characteristics of the fuel (Pestes and Stanislao, 1984; Ryan et al., 1984). On a positive note, when the Simarouba glauca...
biodiesel was blended with conventional diesel fuel, the viscosity was decreased to within expectable standard levels (see Table 4).

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Fuel properties for the conventional diesel fuel tested and the blends of Simarouba glauca biodiesel and the conventional diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cal content</td>
</tr>
<tr>
<td>Diesel</td>
<td>37,100.089</td>
</tr>
<tr>
<td>B5</td>
<td>36,446.708</td>
</tr>
<tr>
<td>B10</td>
<td>36,287.804</td>
</tr>
<tr>
<td>B20</td>
<td>34,436.499</td>
</tr>
<tr>
<td>B50</td>
<td>32,716.527</td>
</tr>
<tr>
<td>B100</td>
<td>32,143.18</td>
</tr>
</tbody>
</table>

The density (867 kg/m³) of the Simarouba glauca biodiesel fell in the desired range given by the European Standard (860–900 kg/m³). However, in order to conduct the fuel performance test in the diesel engine the density for each blend was required and it was found that as the amount of conventional diesel fuel was increased the density was reduced. None of the density for the blends met the European standard quality.

The flash point for the Simarouba glauca biodiesel of 160 degrees Celsius was higher than the minimum given in both the European standard (> 120 degrees Celsius) and American Standards (> 130 degrees Celsius) (National Biodiesel Board, 2009). The flash point of the Simarouba glauca biodiesel was also higher than that of Jatropha curcas and soybean biodiesel, but not higher than that of oil palm biodiesel (Gui et al., 2008). The cloud point was higher than most values compared and so was the pour point. However, they were comparable to that of oil palm oil, a very popular feedstock in the tropic areas. Cloud point testing was performed for all the Simarouba glauca biodiesel blends and as the percent of conventional diesel fuel was increased the cloud point temperature was decreased.

The SV and iodine number of the Simarouba glauca oil was compared to a previous study. The previous study found the SV and iodine number of expelled Simarouba glauca oil to be 192.3 and 52.8, respectively (Sahoo et al., 2002). That was similar to the values our research found for the SV (185.93) and iodine number (54.28) of the Simarouba glauca oil. The calorific content of Simarouba glauca biodiesel was 32,143 MJ/kg, which was lower than the calorific content of Jatropha curcas biodiesel (39,230 MJ/kg) and soybean biodiesel (39,760 MJ/kg) (Gui et al., 2008). Furthermore, this was the other fuel property that was required for the fuel performance test in the diesel engine and was determined for all the Simarouba glauca biodiesel blends with conventional diesel fuel. Results showed that as the proportion of conventional diesel was increased so did the calorific content.

5 Conclusions and policy implications

This study attempted to determine how efficient the production process of a community-based biofuel feedstock collection and conversion program, involving Simarouba glauca, in Karnataka, India was. We analysed three major processes involved in the biodiesel production system: seed decortication, oil expelling, and
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transesterification. Furthermore, we determined fuel properties for the Simarouba glauca biodiesel and oil produced in the test case. The fuel properties were then compared to popular feedstock and quality standards. While the Simarouba oil and biodiesel did not meet all the technical conversion and fuel performance standards of the US and EU, some of the specifications were encouraging. Especially, when the oil was mixed with conventional diesel, the results were more encouraging than the stand alone Simarouba oil.

While Simarouba glauca shows promise for being a feedstock for the small scale production of biodiesel in India, it is important to remember the cautionary case of Jatropha curcas (Ariza-Montobbio and Lele, 2010). Currently, plantations of Jatropha curcas are gaining popularity again on small scales, despite all the criticism. However, further research is needed before recommending Simarouba glauca for use as a feedstock for the large scale production of biodiesel (Achten et al., 2010). KSBDB and UAS continue to promote the expansion of the district- and village-level feedstock development networks not only for Simarouba but also for other oilseed crops. In order for such program to succeed in terms of technical efficiency, the government may consider bringing more technical, organisational and financial resources to bear.

First, there is more room for improvement in the technical efficiency of decorticators, oil expellers and biodiesel machines. Unless the government takes a proactive approach in helping small oilseed growers associations, many of them lack the technical knowledge to acquire and maintain high efficiency machines. Necessary financial help – in the form of subsidised loans – may be extended to rural associations to install such machines. Many such small associations lack the financial wherewithal to purchase such equipment on their own. Second, farmers need training in implementing best practices for oilseed collection, drying and curing. Often times, farmers may not know the non-edible oilseed crops which are suited to their farm environment. The network of biofuel research parks and district level biofuel information centres can play a significant role in providing such training. There exists a much larger agricultural extension network in Karnataka State. The state extension may take part in the training program as well.

Finally, we recognise that the success of the rural decentralised biofuel feedstock program depends on forces beyond the conversion technology. There are other economic challenges that the rural feedstock development program is confronting. The market for non-edible oil and biodiesel is still in its infancy. KSBDB is working hard to establish reliable buyers such as state transportation corporations. However, some of the farmers associations are still wary about the oilseed and vegetable oil markets. The state and national government may want to establish minimum support price to protect the oilseed growers’ bottom line. However, in the long-run the price support program may not be sustainable without a robust market for biodiesel or vegetable oil. There are efforts to mandate minimum vegetable oil blend with conventional diesel. This might help keep the demand for biodiesel at a steady state. Farmers and their associations should also be allowed to sell their oilseeds or oil to the highest bidder or to a buyer from a different state. They should have a freedom of choice to whom and for how much to sell their oilseeds. Since the goal of producing biofuels in India is to become energy independent export of biodiesel is controversial. Initially, biodiesel should only be utilised in the domestic market to help rural areas with production and generation of their own energy. This will not only help ease the rural energy demand, but also will encourage rural investment in the biodiesel market.
Acknowledgements

The funding for this research was made possible by the grants from the US Department of Agriculture (USDA-HSI Grant# 2010-38422-21261 and USDA-ISE Grant# 2008-51160-04356) and grants from the Government of Karnataka, India, and KSBDB. The authors would like to thank K.T. Prasanna, Rajesh Kumar, Thelma Velez, Stephany Alvarez-Ventura, and Braian Tome for advice and assistance.

References


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