

## Towards Valorization of Baobab for the Production of Biofuels

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### ABSTRACT

Baobab (*Adansonia digitata*) is a promising bio-resource distributed across Africa. A variety of biofuels such as biodiesel, bioethanol, bio-oil and biogas can be prepared from feedstock derived from baobab. In this vein, different parts of baobab plant, for instance oil, fruit shells, and seed cakes can be utilized for biofuel synthesis. In this study, novozyme-435 (CAL-B) was used as a biocatalyst for biodiesel production. Oil to biodiesel conversion of 91.8±2.6% was obtained within 6 h reaction time at 50 °C when the molar ratio of oil to methanol was maintained at 1: 3. Biocatalysts are non-toxic and biodegradable, therefore sustainable for the process. The results showed potential use of baobab oil as a feedstock for biodiesel production.

**Keywords:** *Adansonia digitata*, biodiesel, lipase, biorefinery, sustainability

### INTRODUCTION

Demand for energy is increasing worldwide due to fast pace of industrialization and continuous increase in human population (Sarkar et al., 2012). Consequently, more pressure is being exerted on conventional energy sources (International Energy Agency, 2010). There are alarming concerns over energy security due to increasing demand for fossil energy which is a finite resource. Additionally, combustion of fossil fuels emits greenhouse gases which have been reported to contribute to environmental pollution (Zabed et al., 2017). In order to enhance energy security and environmental sustainability, search for alternative energy sources must be accelerated. Along this line, biomass is one of the feasible and promising sources for alternative energy due to its abundance and sustainability (Yang et al., 2016). Biomass can be converted into various solids, liquids, and gaseous biofuels. Furthermore, biofuels contribute for less greenhouse gas emissions as compared to fossil fuels (Ellabban et al., 2014).

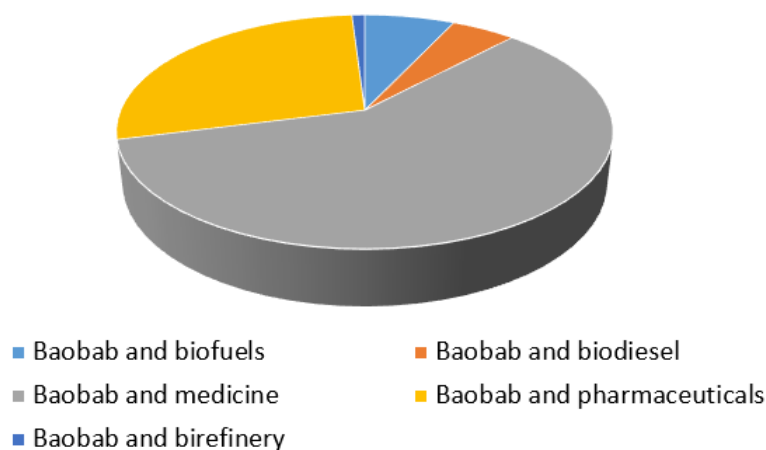
Across the world, different countries have shown interest for the development of renewable fuels. Biodiesel, a viable alternative to petroleum diesel, is one of the major biofuels receiving increasing attention in Africa (Rawat et al., 2014). Biodiesel is produced from plant oils, animal fats and grease (Karmee, 2016). Presently, the most promising energy crop for biodiesel production in Africa is *Jatropha* (Von Maltitz et al., 2009; International Energy Agency, 2010; Walimwipi et al., 2012). The other promising feedstocks are: castor, coconut,

palm, sunflower and soybean oils (Von Maltitz et al., 2009; Walimwipi et al., 2012).

To sustain biodiesel production sector in Africa; it is pertinent that scope of feedstock utilization is diversified. Therefore, different feedstocks need to be identified and tested for their biodiesel production potential to reduce overdependence on few resources. Africa is rich in plants with high oil content which have minimal or no commercial applications; hence, these could be utilized for biodiesel production. Some of the oil bearing plant species available on the continent include *A. digitata*, *Croton megalocarpus*, *Khaya senegalensis*, *Hura crepitans* L., *Azelia africana* and *Calodendrum capense* (Aliyu et al., 2010; Phahladira et al., 2012; Ogbu and Ajiwe, 2016).

### Other Potential Biofuels from Baobab Residues

In addition to biodiesel, other biofuels including bioethanol, biogas and bio-oil can also be prepared from by-products/waste generated from the baobab plant. Baobab seedcake and fruit shells can be used to produce bio-oil and bioethanol. Bio-oil is a liquid fuel that can be used for heat and electricity generation in boilers, furnaces, turbines and diesel engines. It can also be upgraded to liquid and gaseous transportation fuels. Bio-oil also serves as a feedstock for producing various chemicals such as food flavouring, specialties, resins, agricultural chemicals and fertilizers. Baobab de-oiled seedcake can be utilized for biogas production.



**Figure 1.** Scientific publications of baobab topics (Source: Science Direct, 2010-2020)

Although baobab has a vast potential to be utilised as a feedstock for biofuels production, such biorefineries are not yet established in Africa (Belyazid et al. 2019). It is reported that sugar content in baobab ranges of 466-877 g/kg in baobab samples from Tanzania and South Africa. This shows that it has a great potential for bioethanol production (Parkouda et al. 2012). So far, research on baobab is carried out in lab scale and utilization of baobab as a feedstock for the production of biofuels in pilot scale needs to be carried out. Pilot scale trial experiments to produce biofuels from baobab will attract investment from industries.

*A. digitata* is a tree belonging to the Malvaceae family and the genus *Adansonia* (Rahul et al., 2015; Venter et al., 2011). The tree is also known as “monkey bread tree” or “upside-down tree” or “baobab” in some parts of the world (Sidibe et al., 2002). Baobab grows naturally without cultivation throughout the African continent (Egbadzor, 2020). The fruit of this tree bears a yellowish-white acidic powder usually known as fruit pulp. It is estimated that 1 kg of fruit can produce nearly 1700-2500 seeds (Sacande et al., 1995). The seed kernels contain golden yellow oil that can be obtained through screw pressing method (Ibrahim, 2016).

Oil yields ranging between 13 wt % and 45 wt % have been obtained from baobab seeds by several researchers (Chindo et al., 2010; Donkor et al., 2014; Nkafamiya et al., 2007). The oil is usually extracted via soxhlet extraction method. In a study by Donkor et al. (2014) 13 wt % oil was obtained through soxhlet extraction with hexane, while extraction using petroleum ether produced approximately 29 wt % oil. Chindo et al. (2010) obtained oil yield of 33 wt %, while Nkafamiya et al. (2007) obtained 45 wt %. Both studies used petroleum ether as the extracting solvent.

Research has shown that fatty acid composition of the substrate affects the fuel properties of the obtained biodiesel (Lin et al., 2011; Razon, 2009). The composition of fatty acids in the feedstock is a crucial determining factor for a biodiesel producing biomass. Generally, palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2) and linolenic (C18:3) acids constitute the dominant fatty acids found in traditional biodiesel feedstock, such as, sunflower, rapeseed and soybean oils (Lin et al., 2011). As depicted in **Table 1**, baobab seed oil is rich in C16:0, C18:0, C18:1, and C18:2 fatty acids. Thus,

**Table 1.** Fatty acid composition of *A. digitata* oil (Komane et al., 2017; Modiba et al., 2014)

Fatty Acid	Content (wt %)	Content (wt %)
C16:0	28.8	21
C18:0	4.4	20.3
C18:1	25.1	22.1
C18:2	36	27.5
C18:3	0.5	8.8

baobab seed oil has potential to serve as a feedstock for biodiesel synthesis.

Although it has been reported that biodiesel can be produced from biomass oils, little is known regarding the potential of the majority of plant seed oils as feedstock for biodiesel production. In this regard, research on baobab is limited and the plant is underutilized even though it is widely distributed across Africa. **Figure 2** shows baobab related research publications over a decade. This clearly shows the limited number of publications on the potential use of baobab as substrate for biodiesel production as well its biorefinery approach. Hence, this article presents an overview on utilization of *A. digitata* plant residues as a viable feedstock for biodiesel production and its potential use for a biorefinery.

## MATERIALS AND METHODS

Baobab seed oil was purchased from Nautica Organic Trading Company, Durban, South Africa. The oil was analysed for its fatty acid profile using Gas chromatography (GC) technique.

Experiments carried out in this study involved screening of lipases from different sources and optimization of reaction conditions viz., oil to methanol molar ratio, temperature, and reaction time.

Each experiment commenced with the addition of lipase into a 50 ml pear-shaped reaction flask, followed by addition of oil. To this mixture was then added an appropriate amount of methanol depending on the desired oil to alcohol molar ratio. The reaction vessel was then capped, clamped to a stand, and immersed into a pre-heated oil bath. The transesterification protocol was adopted from Karmee (2016).

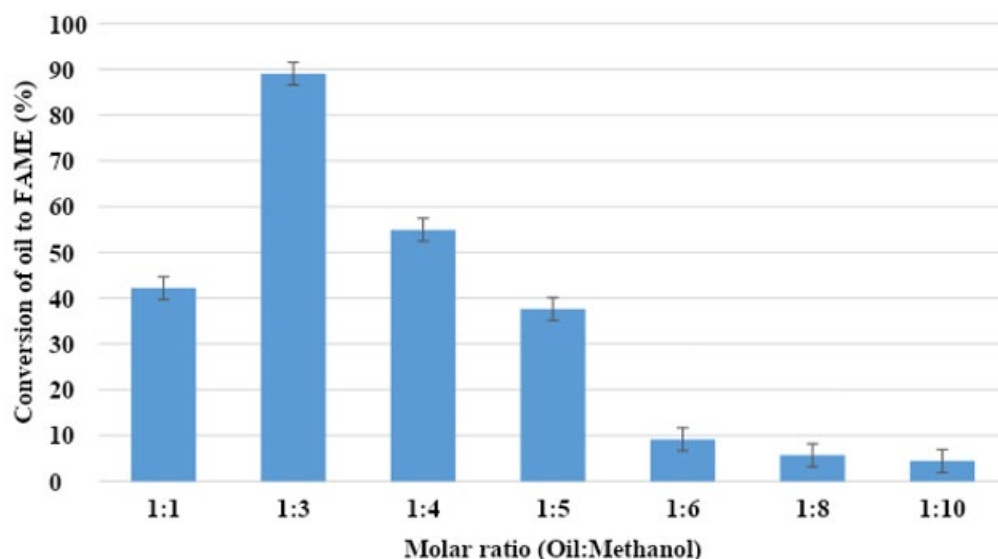


Figure 2. Effect of oil to methanol molar ratio on lipase-catalysed methanolysis of baobab seed oil

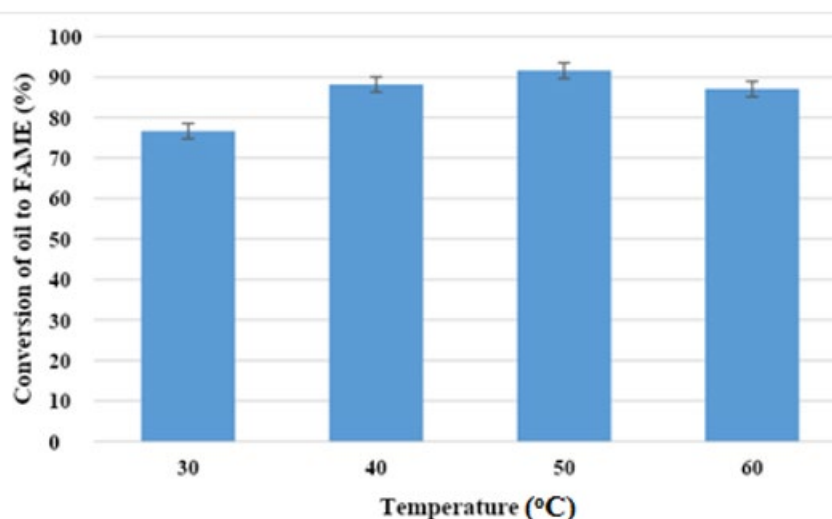


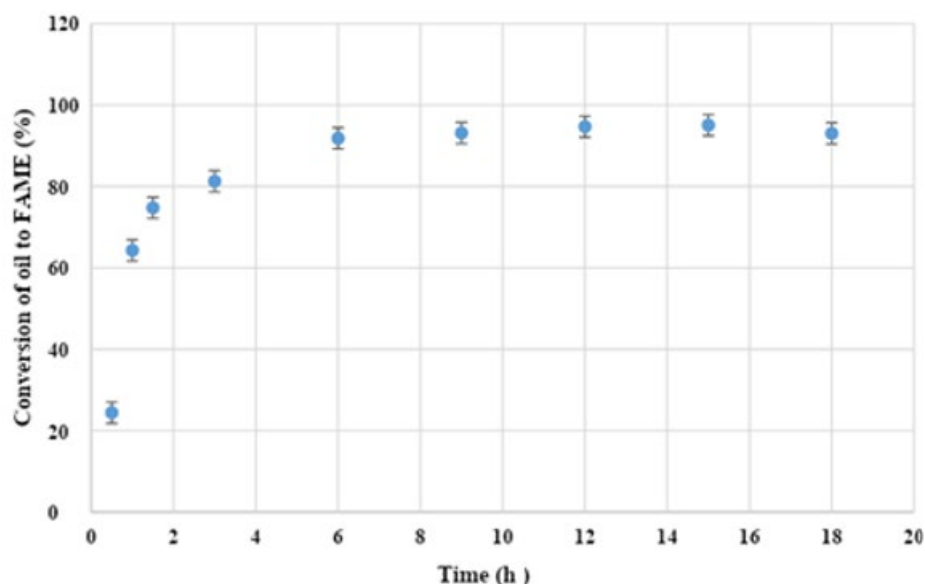
Figure 3. Effect of operating temperature on lipase-catalysed methanolysis of baobab seed oil

Baobab seed oil was analysed using a gas chromatograph equipped with a flame ionization detector (FID) to determine its molecular weight and fatty acid profile. An Agilent 7820A GC system was used for the quantification analysis. The instrument is equipped with a 100 m HP-88 capillary column and uses helium as carrier gas. Operating conditions used for GC-FID analysis included 1 µl injection volume as well as inlet temperature and pressure of 250 °C. The FID temperature was kept at 350°C with detector gas flow of hydrogen (H<sub>2</sub>): 40 ml/min; Air: 400 ml/min.

## RESULTS AND DISCUSSION

The feasibility of baobab seed oil as feedstock for biodiesel production has been investigated by Modiba et al. (2014). In this study, baobab seed oil was transesterified with methanol in presence of NaOH as a homogeneous catalyst to produce biodiesel. At 60 °C, the reaction was optimized using 30 wt % methanol with respect to oil and 1.4 wt% catalyst to oil ratio yielded 96 wt% biodiesel after 1 h of reaction.

A study by Chilabade (2017) showed that biodiesel production from baobab seed oil *via* lipase-catalysed transesterification is feasible. The fatty acid profile was used to compute the molecular weight of the oil. The molecular weight of the baobab seed oil used in this study was calculated to be 577.58 g/mol. For this purpose, several lipases viz. *Candida antarctica lipase-B*, *Porcine pancreas*, *Candida sp.*, *Candida rugosa* and *Pseudomonas fluorescens*, were screened. The results showed *Candida antarctica lipase-B* as the best catalyst for highest conversion of baobab seed oil to biodiesel. Chilabade also assessed the effects of various reaction conditions including oil to methanol molar ratio, temperature, and time on methanolysis of baobab seed oil catalysed by 10 wt % *Candida antarctica lipase-B* and the results are presented in **Figures 2-4**. A 91.8±2.6% conversion of oil to biodiesel could be achieved under optimized conditions of 1:3 feedstock to methanol molar ratio, 50°C, and 6 h of reaction time. These findings are similar to outcomes from a study by Lamayi et al. (2016). In their study, oil was transesterified using absolute ethanol and KOH as catalyst. It was observed that optimum conditions yielded 96 % biodiesel.



**Figure 4.** Effect of reaction time on lipase-catalysed transesterification of baobab seed oil

**Table 2.** Comparison of fuel properties of baobab biodiesel with ASTM D6751-02 and EN 14214 biodiesel specification standards (Modiba et al., 2014)

Fuel properties	Baobab	ASTM D6751-02	EN 14214
Kinematic viscosity (mm <sup>2</sup> /s)	4.46	1.9-6.00	3.5-5.0
Density (Kg/m <sup>3</sup> )	882	860-900	860-900
Flash point (°C)	192	>130	>120
Pour point (°C)	-1	-15-10	-
Cloud point (°C)	2	-3-12	-
Oxidation stability (h)	3.09	>6	>3
Cetane number (min)	57	47	51

### Biodiesel Quality

Modiba and co-workers compared fuel properties of the biodiesel synthesized from baobab seed oil with ASTM D6751 and EN 14214 biodiesel specifications (Modiba et al., 2014) (Table 2). The tested fuel properties satisfied the specifications except for oxidative stability which did not conform to ASTM D6751 standard. However, oxidation stability of biodiesel fuels can be enhanced by various antioxidant additives which are readily available commercially.

The calorific value of baobab biodiesel was found to be 36.92 MJ/kg. Ultimate analysis indicate the presence of C (68.6%), H (10.12%), and O (26.96%) in the prepared biodiesel fuel.

### Future Prospects of Baobab in Africa

The sales of co-products, such as seed oil and cake for food and nutrition security have increased economic viability in countries such as Côte d'Ivoire, Kenya and Sudan (Akpata et al., 2013; Ali et al., 2018; Gebauer et al., 2002). These countries also use the pressing method to obtain oil from the seeds, which is exported to cosmetic industries (Europe, United States of America). Baobab has been envisaged to increase biodiesel yield due to its high oil content. However, developing a baobab-based refineries in Africa will require a careful assessment of the supply chain and life-cycle to avoid unforeseen consequences. Production of multiple products from the baobab based biorefinery could increase the

economic viability of the complete process and different products obtained from it.

Even though baobab has not been fully explored for biofuel production in Africa, other promising feedstock for biodiesel production in Africa are oil palm and Jatropha, which were proposed in Nigeria; whereas, soybean, sunflower, and canola were proposed as feedstock in several countries including South Africa. Overall, more research as proof-of-concept for baobab as feedstock for biofuel production is required to subsequently apply the laboratory tested concepts for pilot scale production. Pilot scale demonstrations will determine the scaling-up potential and will prove viability of baobab as feedstock.

## CONCLUSIONS

Currently, *A. digitata* has limited commercial applications. Considering the energy generation crisis in most African countries, *A. digitata* has a potential to be used as feedstock for biofuel production. In the present paper, baobab seed oil was successfully converted to biodiesel in high yield. An optimum oil to biodiesel conversion of 91.8±2.6% was obtained with 10 wt % *Candida antarctica* lipase-B lipase enzyme catalyst, 1:3 feedstock to methanol molar ratio, at 50°C for 6 h of reaction time. Valorisation of by-products and waste materials derived from the baobab plant could also generate other important biofuels including bioethanol, biogas, and bio-oil. These

findings could pave future research for wide adoption of baobab as a feedstock for biodiesel production.

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**Declaration of interest:** There is no potential conflict of interest by authors.

**Ethics approval and consent to participate:** Not applicable.

**Availability of data and materials:** All data generated or analyzed during this study are available for sharing when appropriate request is directed to corresponding author.

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