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Research paper

Actual and putative potentials of macauba palm as feedstock for solid biofuel production from residues

Anderson Barbosa Evaristo [a,*], José Antonio Saraiva Grossi [a], Angélica de Cássia Oliveira Carneiro [b], Leonardo Duarte Pimentel [a], Sergio Yoshimitsu Motoike [a], Kacilda Naomi Kuki [a]

[a] *Departamento de Fitotecnia, Universidade Federal de Viçosa, Viçosa, MG 36570-900, Brazil*
[b] *Departamento de Engenharia Florestal, Universidade Federal de Viçosa, Viçosa, MG 36570-900, Brazil*

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ABSTRACT

The making of biofuel from source that aggregates multiple suitable raw materials is of great interest. An example of such source is macauba palm. Its fruit satisfies the demands for biodiesel production, and the solid residues resulting from its processing contain a series of potential fuel byproducts. Thus, our objective was to evaluate macauba fruit yield and the potential of this fruit to produce for solid biofuel. For this, the palm's productivity was assessed in a natural population, and two different scenarios of fruit yield and derived residues were analyzed: in scenario 1, the fruit yield average values were used without *a priori* information, while in scenario 2, the top 10% of plants in terms of number of bunch per plant were considered. Harvested fruits were quantified and processed. Solid residues had their chemical and physical characteristics determined. The fruit yield in scenario 2 was 98% higher than that in scenario 1, which did not exceed 2.32 Gg km^{-2} y^{-1} fresh fruit. Regarding residue characterization, the endocarp showed higher values of fixed carbon, lignin, bulk density and energy density than the other residues. The overall primary energies of the residues were 23.35 TJ km^{-2} y^{-1} and 44.39 TJ km^{-2} y^{-1} in scenarios 1 and 2, respectively. These findings indicate that macauba fruit is a promising source of primary and residual raw materials for biofuel production. Satisfactory production scale would be from a breeding program to maximize the fruit production of the plants, as mimicked by scenario 2.

1. Introduction

The quest for global sustainability demands that society adopt a new perspective on production systems, particularly the supply and use of energy. Studies have shown that replacing fossil fuels by biofuels reduces greenhouse gas emissions [1,2]. However, biofuel production from energy crops can have negative environmental impact, such as land use change, especially if annual crops replace forested areas [3]. Therefore, the use of perennial arboreal species for a more sustainable production chain of bioenergy agriculture is promising [4–6].

In tropical regions, oil crops such as soybean, sunflower and African palm (*Elaeis guinensis* Jacq.) are good choices for biodiesel production [7,8]. However, these crops are grown primarily for food production, and the biodiesel sector can only utilize the oil that exceeds the food demand because of the higher market value of oil for food use. Therefore, oleiferous perennial plants such as jatropha (*Jatropha curcas*) and macaúba (*Acrocomia aculeata*), whose oils are not traditionally consumed by humans, have been studied as alternative feedstocks for biodiesel production [7,9,10].

In Brazil, most (approximately 78%) of the raw material for biodiesel production comes from soybeans, whose main product is a protein-rich meal used for animal feeding [11]. Thus, the potential for bioenergy production could be increased by extending biodiesel production into non-edible oleiferous crops. As an encouragement for biodiesel production and consumption, Brazil has launched various acts, such as federal legislation demanding the use of 7% biodiesel blended with petroleum diesel and the National Program for Production and Use of Biodiesel. This program has two main goals: 1) the enhancement of oleaginous crops cultivation by small farmers; and 2) diversification of raw materials. Macauba palm can

* Corresponding author. Departamento de Fitotecnia, Universidade Federal de Viçosa, Av. P.H. Rolfs, Campus, Viçosa, MG 36570-000, Brazil.
E-mail address: evaristo.ab@gmail.com (A.B. Evaristo).

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fill these voids; besides the oil, the co-products obtained after fruit processing could be used to produce biogas, bio-oil, bio-kerosene, second-generation ethanol and solid biofuels to generate electricity and steam, increasing the supply of bioenergy [4,12–17].

Vegetable oil extraction rate of traditional raw materials, such as oil palm and soybean, ranges from 18 to 22%. Typically, the processing of these crops results in, on average, 80% of by-products. Considering crops with specific purpose for bioenergy production, it would be desirable that the co-products (residues) could also be used to generate energy. With that approach, energy productivity would improve considerably. That way, this residues can be used as a raw burning material or transformed in to a variety of biofuels, such as pellets, coal, bio-oil and bioethanol. The prospect of utilizing the lignocellulosic residues in such ways is attractive because it is expected to have environmental and economic benefits.

In Brazil, as all around the world, most of the biodiesel comes from oil crops grown for human consumption, among them the African palm, recognized as the most productive oil crop in the world [20]. In this regard, rational exploitation of other oleaginous palms with competitive potential could lessen the conflict inherent in using food crops as fuel. The estimated productivity of the macauba palm (*Acrocomia aculeata*) is similar to African palm, but it has the advantage of being suited to edaphoclimatic zones, which feature conditions averse to African palms, such as a lower annual rainfall and a wider temperature range [16,21]. The macauba palm is native to the Neotropical Americas and produces large bunches of drupaceous fruits composed of tough and fibrous epicarp, fleshy pulp, and a nut consisting of a lignified endocarp and kernel [22].

The great interest in this species as a raw material for biodiesel is based on its high fruit yield (approximately 62 kg per plant), the high oil content in the pulp (45%–60%, dry matter) and kernel (61%–68%, dry matter), and on its high oil quality [23–25]. However, when processing macauba fruits for oil, several residues are generated in large amounts: husk (epicarp), pulp cake (mesocarp), endocarp and kernel cake. These residues biomaterials may also be used as sources for different biofuels, adding value and turning the palm into a truly sustainable and profitable crop. Within this context, it is essential to characterize the physico-chemical properties of the residues, which can directly influence the effectiveness of the processes.

The results of this characterization would allow the prediction of the productivity, analysis of the technical and economic feasibility, and optimization of technologies for converting biomass more efficiently. Therefore, to support the use of macauba as a raw material for solid biofuel production, our objective was to evaluate the yield potential of the specie, determining fruits and primary energy yield. Additionally, we evaluated physical and chemical properties of the biomass generated during fruit processing.

2. Materials and methods

2.1. Plant materials and harvesting site

Bunches of mature fruits from macauba palm were harvested from randomly selected adult plants (5 m to 14 m height) of a native population (Fig. 1A) growing in the municipality of Mirabela - Minas Gerais state, Brazil (16°29′55″ S, 44°04′14″ W, datum WGS 84). A sickle attached to an aluminum pole was used to detach the bunches from the mother tree. After harvest, fruits were sorted, withdrawing damaged and broken fruits, and then homogenized to form the experimental units. Each experimental unit was composed of 100 fruits.

Fruits were sent to the Laboratory for Macauba Biotechnology and Postharvest where they were processed. The constituent parts of the fruit (husk, pulp, endocarp and kernel) were manually separated, measured and subjected to physical and chemical analyses (Fig. 1B). Moisture content of each part and residues was determined by drying the samples at 105 °C until reaching a constant mass, according to the methodology described by the European Committee for Standardization (method number CEN/DIN 14774-3; [26]). The oil contents of the pulp and kernel were quantified by nuclear magnetic resonance according to the ISO 10565 protocol [27], and the oil extractions were accomplished by a stainless steel hydraulic press (Fig. 1C and D). Before performing the analyses, pulp and kernel residues were submerged in hexane for 48 h to remove fat. At a 12-h intervals, sub-samples were collected and analyzed for oil content by the RNM method to check if residual oil was still present. When pulp and kernel residues were oil-free, the samples were removed from the hexane and dried at 105 °C. (Fig. 1E and F). The other parts of the fruits, i.e, the dried husk and endocarp, were directly analyzed (Fig. 1G and H). After fruit processing, the proportion of residue generated in relation to the fruit (PRF) was calculated as the amount of mass (dry matter) of each fruit residue relatively to the whole fruit mass (dry matter) according to the equation: $PRF = M_{residue}/M_{fruit}$, in which $M_{residue}$ is the mass of residue (e.g., husk) and M_{fruit} is the mass of fruit.

2.2. Higher heating value), lower heating value), bulk density) and energy density

The higher heating value (HHV) of the residues were individually determined according to the method described by ASTM standard D 2015-77 [28] using an adiabatic bomb calorimeter. Meanwhile, the HHV of the whole fruit (HHV_{fruit}) was calculated as:

$$HHV_{fruit} = (HHV_{husk} \times PRF_{husk}) + \left(HHV_{pulp\ \ cake} \times PRF_{pulp\ \ cake} + HHV_{pulp\ \ oil} \times M_{pulp\ \ oil}\right) + \left(HHV_{endocarp} \times PRF_{endocarp}\right) + (HHV_{kernel\ \ cake} \times PRF_{kernel\ \ cake} + HHV_{kernel\ \ oil} \times M_{kernel\ \ oil})$$

In which

HHV_{fruit} = higher heating value of the whole fruit (MJ kg^{-1})
HHV = higher heating value (MJ kg^{-1})
PRF = proportion of residue generated in relation to the fruit (kg kg^{-1}).
$M_{pulp\ oil}$ = mass of pulp oil contained in the fruit (kg)
$M_{kernel\ oil}$ = mass of kernel oil contained in the fruit (kg)

The lower heating value of the fruit residues (LHV) was calculated according to equation below considering 0.1 kg kg^{-1}moisture work (W; average hygroscopic moisture under equilibrium for this particular biomass) for all residues:

$$LHV = [(HHV - \gamma(W + 9H))(1 - W)]$$

where

LHV = lower heating value (MJ kg^{-1})
HHV = higher heating value (MJ kg^{-1})
γ = latent heat of water = 2.31 MJ kg^{-1} at 25 °C
H = hydrogen content (kg kg^{-1})
W = sample moisture content (kg kg^{-1})

To determine the bulk density (BD) of the residue, each residue was placed in a rigid plastic box of known volume and weighed. The BD was calculated according to the ABNT NBR 9165 method [14].