Energy Characterization of Wood and Charcoal from Savannah Forest Species

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The objective of this study was to evaluate the energy potential of *Astronium fraxinifolium* and *Enterolobium gummiferum* wood species that grow in the Savannah of Minas Gerais, Brazil, focusing on the production of charcoal. Two discs were removed at 1.30 m from the ground of three trees of each species, and these were later sampled into wedges that were applied in the analysis of wood characteristics and charcoal production in a muffle furnace. The extractives content and basic density of the wood species were determined, and apparent density of charcoal, ash content, heating value, and energy density of both materials were also determined. The woods under study have potential for application in energy production. Emphasis was placed on *A. fraxinifolium*, which presented wood and charcoal that was denser, had higher energy density, and achieved greater gravimetric yield.

DOI: 10.15376/biores.18.1.1780-1787

Keywords: Energy density; Heating value; Gravimetric yield; Renewable energy

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INTRODUCTION

Brazil is the largest producer and consumer of charcoal in the world. Part of the material comes from planted trees, such as the *Eucalyptus* genus, and the other comes from native wood species from different Brazilian regions (IBÁ 2022). Charcoal is primarily employed in the steel industry and cast iron, in which its function is to provide heat for combustion, to indirectly supply carbon, which is the main alloying element of pig iron, in addition to providing carbon itself for the reduction of iron oxides (Jacomino *et al.* 2002). It also contributes as an alternative energy source to fossil fuels in other national sectors: industrial, commercial, agricultural, and residential areas (BEN 2021).

Charcoal is produced from wood *via* carbonization. Its quality is directly related to the parameters used for the carbonization process, such as the heating rate, final carbonization temperature, and oven pressure (Rousset *et al.* 2011; Vieira *et al.* 2013). The charcoal quality also depends on the characteristics of the wood, which influence the quality and yield of charcoal (Assis *et al.* 2016). Given that the properties of hardwoods impact the yield of charcoal and its physical, chemical, and mechanical properties (Dufourny *et al.* 2019; Couto *et al.* 2022), research on the quality of native wood for energy purposes is necessary. Brazilian Savannah is the second-largest biome in Brazil and is noted for its high number of tree species and biomass production. Thus, studies with wood

species from this biome can help in its sustainable management plan and the introduction of little-known trees with high energy potential in the market. *Astronium fraxinifolium* Schott and *Enterolobium gummiferum* (Mart.) J.F. Macbr., for example, are native and endemic species of the Savannah, with a high potential for reforestation and management of degraded areas (Pilon and Durigan 2013; Calgaro *et al.* 2015). In addition, their wood already has commercial value for civil construction and structural purposes. It represents a viable option for planted forests and sustainable management, and may have potential for energy purposes and thus add value to the biome and region.

In this context, considering the wide availability of these species' trees and that charcoal quality is directly correlated with properties of the raw material, the present study aimed to evaluate the energy potentials of *A. fraxinifolium* and *E. Gummiferum* from the energy characterization of wood and charcoal.

EXPERIMENTAL

Material Collection and Sample Preparation

Two discs with 5 cm of thickness were cut from three of *Astronium fraxinifolium* trees at 1.30 m above ground level in the Montes Claros, Minas Gerais, Brazil. And two discs were cut from three of *Enterolobium gummiferum* trees and were collected in the Carbonita, Minas Gerais, Brazil. Both species came from an area of remaining vegetation characterized as the seasonal semideciduous forest of the Savannah biome.

The disks from each tree were divided perpendicularly into four wedges. Two opposing wedges were used to determine wood basic density. The other wedges were sampled for wood chemical and energy analysis, charcoal production, and its characterization. Three replicates for each analyzed parameter were carried out.

Wood Carbonization

Carbonizations were performed using an electric muffle furnace. Approximately 300 g of wood previously dried at 105 ± 3 °C was used. The average heating rate to perform the pyrolysis was 1.67 °C/min, according to the methodology of Trugilho *et al.* (2005), which consisted of the initial temperature equal to 100 °C until the final temperature reached 450 °C, and was allowed to stabilize for a period of 30 min. Thus, the carbonization process was carried out in a period of 4 h.

Wood and Charcoal Characterization

For the chemical and energy analysis of the wood, the wood sawdust of mesh size between 40 and 60 was used and determined the absolutely dry content according to TAPPI 264 om-88 (TAPPI, 1997). The total extractive content of wood was determined as specified by TAPPI T204 cm-97 (1997). The extraction was performed with dichloromethane, 1:2 ethyl alcohol-toluene mixture, and ethyl alcohol using a Soxhlet apparatus. The ash content was determined according to TAPPI 211 om-12 (2012), which consisted of quantifying the ash *via* incineration in a muffle furnace at a temperature of 525 ± 25 °C for 3 h.

The basic density of the woods was determined according to NBR 11941 (2003), which consisted of the ratio between the dry mass of the wood and its saturated volume. For charcoal, the apparent density was determined by adapting the methodology of Vital (1984) with replacement of water by mercury. The high heating value of both materials

was determined in an adiabatic bomb calorimeter according to NBR 8633 (1984), and the low heating value was calculated according to Costa *et al.* (2017). The energy density was obtained by the product of the basic density and the superior calorific value. The gravimetric yield in charcoal and carbonization energy yield were calculated according to Protásio *et al.* (2015).

Statistical Analysis

The data were submitted to the Shapiro-Wilk and Levene tests at 5% level of significance to test the normality of the residues and the homogeneity between the variances. Then, analysis of variance was applied using the F test at 5% significance. The analyses were performed with the software R Core Team (2019).

RESULTS AND DISCUSSION

Both wood species showed significant differences for all wood parameters evaluated in this study (Table 1). For the total extractives content, the wood of *E. gummiferum* presented values 1.3 times higher than that of *A. fraxinifolium*. The results were similar to those of *Eucalyptus* (1% to 5%), which is the main genus employed in the forest energy sector (Zanuncio *et al.* 2019; Vieira *et al.* 2021) in Brazil.

Table 1. Wood and Charcoal Characterizations of *Astronium fraxinifolium* and *Enterolobium gummiferum*

Material	Parameters	*A. fraxinifolium*	*E. gummiferum*
Wood	Total extractives (%)	4.89 B	6.44 A
	Ash (%)	1.54 A	0.61 B
	High heating value (MJ kg^{-1})	17.59 A	17.21 B
	Low heating value (MJ kg^{-1})	17.42 A	17.06 B
	Basic density (kg m^{-3})	632 A	548 B
	Energy density (GJ m^{-3})	11.12 A	9.43 B
Charcoal	Ash (%)	5.10 A	1.13 B
	High heating value (MJ kg^{-1})	30.11 A	31.56 A
	Low heating value (MJ kg^{-1})	28.75 B	30.19 A
	Apparent density (kg m^{-3})	461 A	313 B
	Energy density (GJ m^{-3})	13.88 A	9.88 B
	Gravimetric yield (%)	31.82 A	28.54 B
	Carbonization energy yield (%)	54.44 A	52.33 A

Averages for each parameter followed by the same uppercase letter in the same row do not differ statistically by the F-test at 5% of significance.

The nature and diverse composition of extractives and their amounts in the wood determine the biofuel heating value for energy purposes (Dadile *et al.* 2020). In this sense, woods with a high extractive content, such as those in the present study – especially *E. gummiferum*, are indicated to be better for charcoal production. The results for extractives of wood were similar to those presented in the literature for Savannah species, from 4% to 10% (Vale *et al.* 2010; Paes *et al.* 2013).

The wood species studied presented satisfactory ash content for energy purposes. The wood of *E. gummiferum* offered wood ash values 2.5 times lower than *A. fraxinifolium*, and, consequently, lower ash content was observed in the charcoal produced. Thus, it is a favorable species for charcoal production in the steel sector, given that a high percentage of mineral in charcoal can cause segregation during the process (Pimenta and Barcellos 2000). These wood ash values were closer to those described in the literature from Savannah species *viz.*, 0.27% to 2.73% (Vale *et al.* 2002; Siqueira *et al.* 2020).

Astronium fraxinifolium wood presented higher energy potential than *E. gummiferum*. However, for charcoal the highest energy potential was observed for *E. gummiferum* charcoal. This may be associated with the chemical composition of the wood species, considering that the heating value is directly associated with the fixed carbon content of the material, and, consequently, with its potential and energy concentration. Thus, given that the calorific value portrays the effective amount of energy provided by the mass of the fuel (Costa *et al.* 2017), the charcoal of *E. gummiferum* was 1.05 times more energetic than that of *A. fraxinifolium*. All values for high heating value were consistent with the literature values for charcoal from Savannah species, from 30 to 33.36 MJ/kg (Figueiredo *et al.* 2018; Siqueira *et al.* 2020), and from the *Eucalyptus* genus, from 29.29 to 31.77 MJ/kg (Zanuncio *et al.* 2019; Protásio *et al.* 2021).

Regarding the wood basic density, the wood of *A. fraxinifolium* had a specific mass 13.3% higher than that of *E. gummiferum*. For charcoal, *A. fraxinifolium* also showed higher apparent density, which is associated with the higher basic density of its wood, because there is a high correlation between the parameters (Vale *et al.* 2010). However, for both, the mean values were similar to those described in the literature for charcoal from Savannah species, which range from 255 to 475 kg/m^3 (Vale *et al.* 2010; Siqueira *et al.* 2020) and also when compared to *Eucalyptus* charcoal, 255 to 420 kg/m^3 (Castro *et al.* 2013; Zanuncio *et al.* 2019). Thus, the species are within the average required by the energy sector (> 500 kg/m^3), especially *A. fraxinifolium*, has the higher wood density, and a higher density means that the mechanical resistance of the charcoal produced is greater (Protásio *et al.* 2021; Couto *et al.* 2022).

Because the energy density is directly correlated to the density and calorific value of the material, both wood and charcoal from *A. fraxinifolium* presented a greater amount of heat in a given volume in relation to *E. gummiferum*, and also when compared to wood (7.83 to 16.16 GJ/m^3) (Jesus *et al.* 2017; Silva *et al.* 2018), and charcoal of the *Eucalyptus* genus (8.37 to 12.61 GJ/m^3) (Protásio *et al.* 2015; Protásio *et al.* 2021).

For the gravimetric yield in charcoal, as well as carbonization energy yield, *A. fraxinifolium* stood out, being approximately 1.10 times higher for both incomes, thus indicating that it is a species with greater energy potential for charcoal production. However, when analyzing the parameters of density and calorific value, both species studied have the average level required by the charcoal sector. Thus, they can be considered as species with potential for energy purposes, which in consonance with sustainable management can serve as an alternative to species traditionally used in the forest sector.

CONCLUSIONS

1. The species under study present wood with satisfactory properties for energy purposes.
2. *Astronium fraxinifolium* presented wood and charcoal that was denser, more energetic, and with greater gravimetric yield.
3. Thus, the results indicate the energy potential of the wood from two Savannah species, which, in the consonance with sustainable management, silvicultural treatments, and genetic improvement, can be a possibility of association with species traditionally used in the forest sector.

ACKNOWLEDGMENTS

The authors would like to thank the Institute of Agricultural Sciences of the Federal University of Minas Gerais (UFMG), the Research Development Foundation (FUNDEP), the Minas Gerais Research Funding Foundation (FAPEMIG), the Study Group on Wood Technology (GETEM), the Professor Cássia Carneiro, Lawrence Oliveira and members of Wood Panels and Energy Laboratory of Federal University of Viçosa (LAPEM) for research support.

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Article submitted: October 4, 2022; Peer review completed: December 21, 2022; Revised version received and accepted: January 9, 2023; Published: January 18, 2023.
DOI: 10.15376/biores.18.1.1780-1787