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Articles

Physical, chemical and energetic properties of wood from seven species from the Cerrado Tocantinense

Propriedades físicas, químicas e energéticas da madeira de sete espécies do Cerrado Tocantinense

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ABSTRACT

The main objective of this research was to characterize the physical, chemical and energetic properties of wood from seven tree species from the Cerrado Tocantinense: *Terminalia argentea* (Garroteiro), *Enterolobium gummiferum* (Tamboril), *Hymenaea stigonocarpa* (Jatobá-do-Cerrado), *Xylopia aromatica* (Pindaíba), *Tachigali aurea* (Cachamorra), *Vatairea macrocarpa* (Angelim-amaroso) and *Simarouba versicolor* (Mata-menino). According to the Forest Code 12.651/2012, the native species were legally collected through environmental licensing for the suppression of native vegetation, resulting from the opening of roads in the municipality of Gurupi-TO. The wood samples were collected, prepared and subjected to tests to verify their properties such as moisture content, basic density, chemical and elemental composition of the wood and the calorific value of the samples, essential to evaluate their energy efficiency. The data were analyzed using statistical methods, such as analysis of variance and Tukey's test, and correlated using Pearson's coefficient to identify possible relationships between variables. The results show that the species present significant variations in their physical and chemical properties, reflecting different potential applications. The woods with higher density, such as Garroteiro and Jatobá-do-Cerrado, are recommended for the production of charcoal; the analysis of calorific value suggests that species such as Pindaíba and Angelim-amargoso have high energy potential.

Keywords: Density; Lignin; Calorific value; Chemical properties

RESUMO

Esta pesquisa teve como objetivo principal caracterizar as propriedades físicas, químicas e energéticas da madeira de sete espécies arbóreas do Cerrado Tocantinense: *Terminalia argentea* (Garroteiro), *Enterolobium gummiferum* (Tamboril), *Hymenaea stigonocarpa* (Jatobá-do-Cerrado), *Xylopia aromatica* (Pindaíba), *Tachigali aurea* (Cachamorra), *Vatairea macrocarpa* (Angelim-amargoso) e *Simarouba versicolor* (Mata-menino). De acordo com o Código Florestal 12.651/2012 as espécies nativas foram coletadas legalmente através do licenciamento ambiental da supressão da vegetação nativa, proveniente de abertura de estradas no município de Gurupi-TO. As amostras de madeira foram coletadas, preparadas e submetidas a testes para verificar suas propriedades como teor de umidade, densidade básica, composição química, e elementar da madeira e o poder calorífico das amostras, essencial para avaliar sua eficiência energética. Os dados foram analisados por métodos estatísticos, como análise de variância e teste de Tukey, e correlacionados por meio do coeficiente de Pearson para identificar as possíveis relações entre as variáveis. Os resultados mostram que as espécies apresentam variações significativas em suas propriedades físicas e químicas, refletindo diferentes potenciais de aplicabilidade. As madeiras de maior densidade, como Garroteiro e Jatobá-do-Cerrado, são recomendadas para a produção de carvão vegetal, a análise do poder calorífico sugere que espécies como Pindaíba e Angelim-amargoso, possuem elevado potencial energético.

Palavras-chave: Densidade; Lignina; Poder calorífico; Propriedades químicas

1 INTRODUCTION

The Cerrado is the predominant biome in the state of Tocantins, accounting for 87% of the native vegetation (Naturatins, 2023). Among the various uses of these native species, wood stands out as a valuable resource, especially in regions where sustainable management practices can serve as an alternative for local development (Reis et al., 2019).

Since the dawn of humanity, wood has been used in different sectors, being one of the most used raw materials for the production of energy, pulp and paper, rural and urban construction, in the furniture industry, and in pharmacology (Souza et al., 2020).

According to the annual report of the Brazilian Tree Industry (2024), the Brazilian steel industry reached, in 2018, a production of 4.6 million tons of charcoal from sustainable sources. Of this production, 91% was subsidized by reforestation biomass and 9% by native forests. Among the energy properties of wood (higher calorific value, energy density and carbon stock), they are essential parameters to determine the characteristics of energy yield.

Brazil stands out in the world sector as the largest producer and consumer of charcoal, being the largest country in the world in which this input has a large-scale industrial application, as its main destination, the production of pig iron, steel and ferroalloy and metallic silicon, about 94% of the charcoal produced is consumed by the industrial sector (Epe, 2024). In addition, the state of Tocantins is considered the second largest producer of firewood in the northern region, producing about 805,512 m³ of extraction wood and 28,470 m³ of wood from forestry (Marchesan et al., 2020).

For Siqueira et al. (2020), the exploitation and predatory use of species from the Cerrado biome culminate in the scarcity of raw materials potentially linked to the energy and timber sector, this happens due to the lack of technological and anatomical knowledge of these species, this ends up expressing the need for scientific research related to the quality of wood from species from this biome.

In addition, working with licensed native species is essential to conserve the Cerrado and avoid the scarcity of raw materials caused by predatory exploitation. Native wood can be used sustainably through forest management and planned cultivation, ensuring plant regeneration and preservation of the biome, as well as generating income for local communities (Reis et al., 2025).

The quality of wood is entirely related to its use, and the set of chemicals, physical, mechanical, and anatomical properties where they validate its technological characteristics of employability (Souza et al., 2020).

According to Lepage et al. (1986), wood in its chemical composition is a three-dimensional biopolymer composed mainly of cellulose, hemicellulose and lignin. Cellulose, the main component of wood, is chemically defined as a type of very complex carbohydrate, polysaccharide, insoluble in water and formed by large chains of glucose molecules. These polymers form the cellular part of wood and are responsible for most of the physical and chemical properties.

The main physical properties of wood are specific mass (mass by volume), or density, and dimensional stability (contraction and swelling as a function of moisture content), and among the mechanical properties are resistance to compression, bending, tensile, shear, and cracking stresses (Araujo, 2020).

The physicochemical composition of the material directly influences the sustainable production of high-quality biomass, the most important variables are: moisture content, calorific value, volatile materials, ash and energy density, as such variables are influenced by the characteristics of the wood such as: age, density and chemical composition (Soleymani; Shokrpor; Jaafarzadeh, 2023).

Regarding the energy potential of wood, Brazil is the largest producer and consumer in the world, with charcoal being produced from wood via carbonization (Santos et al., 2023). However, this thermochemical process converts biomass into solid, liquid, and gaseous products, using high temperatures to break the chemical bonds of the constituent elements of the cell wall (Danesh et al., 2023).

Thus, the objective of this study was to assess the physical, chemical, and energy properties of wood from seven forest species found in the Cerrado of Tocantins. Additionally, considering that the species are native to the municipality of Gurupi-TO, it is important to note that the taxonomic identification of the collected material was carried out at the species level, making the analysis specific to each evaluated species.

2 MATERIALS AND METHODS

The research was carried out in the Laboratory of Technology and Use of Forest Products, the wood of the seven species was obtained and collected from a vegetation suppression for road construction in the municipality of Gurupi, Tocantins. In accordance with phytosanitary conditions, in an area of the Cerrado *sensu stricto* of the Experimental Farm of the Federal University of Tocantins, on the *campus* of Gurupi-TO under the coordinates 11°46’21.5” S and 49°03’21.9” W, with 29m altitude and the climate according to the Köppen climate system classification model is typically mesothermic, with dry winter (Cwa) and rainy summer (Seplan, 2012).

To evaluate the physical and chemical properties of the seven wood species, the material was selected and the number of samples per species were collected in different positions of the stem such as (Base, DBH and Top) resulting in 70 samples. Thus, the same materials were transformed into chips, toothpicks, then ground and sieved until the particles were obtained, which passed through 40 mesh sieves and were retained in 60 mesh. In addition, samples of wood chips and charcoal were constituted to determine the physical, chemical and energetic properties of the wood.

Lignin is a natural polymer that provides wood with thermal resistance, essential for its efficient carbonization (Elniski et al., 2023). Holocellulose is the sum of cellulose and hemicelluloses and represents 60–80% of the wood's dry mass, meaning that most of the material will be burned and converted into energy (Long et al., 2023). The energy density of wood is the portion of energy released per unit volume of wood; that is, the higher the energy density, the more energy is transported or stored (Silveira et al., 2025).

In laboratory analysis following Wastowski's standard (2018) where it was used to determine the (moisture content, total extractives, total lignin, holocellulose and solubility in NaOH), in which the percentage of water present in the wood in relation to its dry weight, the amount of extractives, lignin and holocellulose and in addition, by the solubility test in NaOH. The standard helps determine the degree of attack on wood by fungi and other xylophagous agents. For the basic density of the wood, the hydrostatic balance method was used following the ASTM D-2395 standard (ASTM, 2022).

To determine the energy properties of wood such as the content of volatile materials, fixed carbon and ashes, the methodology described in the NBR 8112 standard (ABNT, 1986) was used in this research.

To determine the higher calorific value of wood, it was based on the work established by Channiwala *et al*. (2002), according to Equation (1):

$$PCS = (84{,}51 \times CF) + (37{,}26 \times MV) + (1{,}86 \times Cz) \quad (1)$$

where: PCS = Higher calorific value of wood (Kcal/Kg); CF = Fixed carbon content (%); MV = Volatile material content (%); Cz = Ash content (%).

The energy density was calculated according to the methodology of Jesus *et al*. (2017) based on Equation (2):

$$De = (Db \times PCS) \tag{2}$$

where: De = energy density of wood (Kcal/cm³); Db = basic wood density (g/cm³); PCS = higher calorific value of wood (Kcal/Kg).

Following the methodology adapted from Protásio et al. (2013), to determine the carbon stock of wood, the calculation was performed by multiplying the fixed carbon content of wood by the basic density of wood, as shown in equation 3:

$$EC = Dbx\left(\frac{CF}{100}\right) \tag{3}$$

where: EC = carbon stock (Kg/m³); Db = basic density (g/cm³); CF = fixed carbon content (%).

2.1 Statistical analysis of the data

For the statistical analysis of the data, a completely randomized design (CRD) was used, with seven species and one carbonization condition, both to determine the properties of the wood and the energy part of the material.

First, the normality test was performed and then the analysis of variance (ANOVA) was performed, then Tukey's test was applied to validate and compare the means at a 5% significance level, in the statistical program Sisvar. Pearson's correlation analysis, which determines the correlation between the data, was performed in the Rbio program, and the Principal Component Analysis in the Past program.

3 RESULTS AND DISCUSSIONS

3.1 Wood characterization

The average values of the physical, chemical and energetic properties of the wood of seven native species of the Cerrado are presented in Table 1. It is noted that the results of this research evaluate all wood parameters, presenting a significant difference of 5% of significance among the seven forest species of this research.

The basic density of wood is a fundamental parameter in the evaluation of its potential for energy production. For Vivian et al. (2024), wood with higher basic density tends to have higher energy density, that is, it stores more energy per unit volume. According to the literature established by Santos et al. (2020), woods classified as moderately dense, where they are considered ideal for energy purposes. For example, the species *Cenostigma macrophyllum* Tul. (Caneleiro), presented by Araújo *et al*. (2018) corresponds to a basic density of (1.2 g/cm³), being classified as high-density wood, which is indicated for energy production.

According to Medeiros et al. (2016) and the Institute for Technological Research - IPT (1985), the basic density of wood is classified into three categories. Low-density woods have values below 0.50 g/cm³, such as *Enterolobium gummiferum* (0.30 g/cm³) and *Simarouba versicolor* (0.40 g/cm³). Medium-density woods range from 0.50 to 0.72g/cm³, such as *Xylopia aromatica* (0.52), *Vatairea macrocarpa* (0.54), *Tachigali aurea* (0.66), *Hymenaea stigonocarpa* (0.69) and *Terminalia argentea* (0.70). Wood with high density, on the other hand, has values higher than 0.72 g/cm³. Thus, when selecting native species for energy generation, it is necessary preference should be given to those with higher basic density, in order to optimize energy efficiency.

For Ramos et al. (2024), it is noticeable that wood from native species showed a greater variation in basic wood density than the variation presented by commercial species (*Eucalyptus)*. This is explained by the great diversity of native species with the potential to be cultivated for charcoal production.

Table 1 – Average values of the physical, chemical and energetic properties of wood from seven Cerrado species

Wood Parameters	Species							
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	Pr>Fc
Db (g/cm³)	0.70 a (3.12)	0.30 d (1.23)	0.69 a (0.75)	0.52 b (3.33)	0.66 a (23.59)	0.54 b (2.40)	0.40 c (0.76)	*
Lignin (%)	66.34 d (6.79)	74.11 a (12.88)	69.35 c (3.77)	70.88 b (2.91)	75.12 a (1.23)	65.45 d (5.11)	69.88 c (1.12)	*
HOLO (%)	25.49 b (2.54)	16.68 e (2.50)	22.30 c (1.59)	22.13 c (0.92)	20.82 d (0.24)	25.09 b (1.70)	26.79 a (0.18)	*
EXT (%)	8.17 b (2.94)	9.21 a (4.74)	8.35 b (3.52)	6.99 c (2.72)	4.06 d (2.99)	9.45 a (3.87)	4.33 d (4.05)	*
CF (%)	13.4 c (13.06)	14.81 b (27.07)	12.27 d (19.79)	14.72 b (8.71)	15.11 b (15.27)	18.61 a (7.53)	14.59 b (25.63)	*
MV (%)	86.13 b (2.04)	84.10 d (4.77)	87.29 a (2.77)	84.96 cd (1.53)	84.67 cd (2.73)	80.56 e (1.76)	85.07 c (4.38)	*
Cz (%)	0.47 c (9.15)	1.10 a (4.65)	0.44 c (9.33)	0.30 d (10.50)	0.22 e (12.35)	0.83 b (2.70)	0.34 d (5.53)	*
C (%)	47.72 ab (0.66)	47.70 ab (1.53)	47.53 b (0.94)	48.04 ab (0.47)	48.15 ab (0.86)	48.51 a (0.51)	47.99 ab (1.43)	*
H (%)	6.04 ab (0.30)	5.98 ab (0.67)	6.05 a (0.39)	6.03 ab (0.24)	6.04 ab (0.39)	5.96 b (0.25)	6.03 ab (0.61)	*
O (%)	45.07 a (0.67)	44.53 ab (1.55)	45.28 a (0.91)	44.93 a (0.851)	44.9 ab (0.89)	44.01 b (0.56)	44.93 a (1.42)	*
PCS (Kcal/Kg)	4568.5 ab (0.76)	4566.04 ab (1.75)	4547.48 b (1.07)	4603.25 ab (0.53)	4614.90 ab (0.99)	4654.21 a (0.58)	4598.55 ab (1.63)	*
DE (Kcal/cm³)	3180.64 a (0.76)	1372.06 f (1.75)	3136.45 a (1.07)	2372.38 d (0.53)	3059.76 b (0.99)	2506.86 c (0.58)	1853.17 e (1.63)	*
EC (Kg/m³)	332.26 a (0.66)	143.34 f (1.53)	327.83 a (0.94)	247.59 d (0.47)	319.23 b (0.86)	261.28 c (0.51)	193.43 e (1.43)	*

Source: Authors (2025)

Where: (A) = *Terminalia argentea* (Garroteiro); (B) = *Enterolobium gummiferum* (Tamboril); (C) = *Hymenaea stigonocarpa* (Jatobá-do-Cerrado); (D) = *Xylopia aromatica* (Pindaíba); (E) = *Tachigali aurea* (Cachamorra); (F) = *Vatairea macrocarpa* (Angelim-amargoso); (G) = *Simarouba versicolor* (Mata-menino). Db = basic density (g/cm³); HOLO = holocellulose (%); EXT = total extractives (%); CF = fixed carbon (%); MV = volatile matter (%); Cz = wood ash (%); C = carbon (%); H = hydrogen (%); O = oxygen (%); PCS = higher heating value (Kcal/Kg); DE = energy density (Kcal/cm³); EC = carbon stock (Kg/m³). Means followed by lowercase letters represent a statistical difference between them (Tukey's test – P ≥0.05%). Values in parentheses correspond to the coefficient of variation (%). (*) significant at the level of 5% probability (p<0.05).

Regarding *Terminalia argentea* (Garroteiro), for example, studies reveal that its wood products are widely used in civil construction, given that it is heavy and hard wood (Gomes et al., 2014). It also stands out for the use of non-timber products of this forest species, as medicinal use through the vegetative extracts of bark and leaves (Silva; Moral; Sebbenn, 2004; Lorenzi, 2008; Gomes et al., 2014).

According to Deus et al. (2022), in chemical terms, the basic density of wood is based on the reflection of the percentage of its different chemical constituents (cellulose, hemicellulose, lignin, and extractives). In addition, the age, height and diameter of the stem and even the porosity of the wood can influence the chemical composition and the constituent elements of the wood such as (Carbon, Hydrogen and Oxygen). The age of the tree, more juvenile wood generally has a lower density than adult wood because it is closer to the sapwood. Local and environmental conditions of growth, such as poor soils or soils with water deficit, tend to produce wood of higher density, promoting slower growth, the cells are more compacted. The genetics of the species itself also determine its growth pattern, anatomy and cell composition, directly influencing the basic density.

Table 1 shows significant differences in the chemical composition of the wood between the species. The parameters of lignin, holocellulose and extractive content showed divergences between the results of the seven species studied. Only three species showed high values of lignin, *Tachigali aurea* (75.12%), *Enterolobium gummiferum* (74.11%) and *Xylopia aromatica* (70.88%). The species *Simarouba versicolor* (69.88%), *Hymenaea stigonocarpa* (69.35%), *Terminalia argentea* (66.34%) and *Vatairea macrocarpa* (65.45%) presented values below 70%.

The lignocellulose content is essential to optimize energy production, as it directly influences the yield of the process (Abdou Alio et al., 2020). Lignin, in turn, is essential for energy production because during the carbonization process, this substance has thermal resistance, a highly branched three-dimensional structure and rich in aromatic rings that hinder complete degradation at lower temperatures, releasing flammable gases and leaving only residual coal rich in fixed carbon, increasing the fixed carbon content, while holocellulose (cellulose and hemicellulose together), especially hemicellulose, degrades more easily with heat, contributing less to the formation of coal (Costa, 2024; Welter et al., 2024).

Confirmed by Lima et al. (2024), lignin directly contributed to the increase in calorific value and mechanical resistance of solid fuels, due to the high levels of energy generated by the biomass of *Caryocar brasiliensis* Camb. (Pequi).

However, there is inverse relationship between holocellulose and lignin, as the higher the lignin content, the lower its holocellulose content. This explains the reason why the species *Simarouba versicolor* (26.79%), *Terminalia argentea* (25.49%), *Vatairea macrocarpa* (25.09%) and *Hymenaea stigonocarpa* (22.30%) have high levels of holocellulose.

The content of timber extractives for *Vatairea macrocarpa* (9.45%), *Enterolobium gummiferum* (9.21%), *Hymenaea stigonocarpa* (8.35%), *Terminalia argentea* (8.17%) and *Xylopia aromatica* (6.99%) were high. In addition, when compared with the lower results presented by the species of *Simarouba versicolor* (4.33%) and *Tachigali aurea* (4.06%), their values were similar to those of *Eucalyptus* sp. (1% to 5%), which is the main genus used in the forest energy sector (Zanuncio et al., 2019; Vieira et al., 2021) in Brazil.

Wood with higher extractive levels plays a crucial role in energy generation, generally has a higher calorific value, due to the fact that they have a large amount of carbon in their structures (Lima et al., 2020), with emphasis on those originating from phenolic nature, however, in percentage terms they have lower amounts than cellulose contents, hemicellulose and lignin and thus, their influence on energy generation is less noticeable, but it is essential (Figueiredo et al., 2024).

In relation to fixed carbon, volatile materials, ash content, the species showed divergence in their data, *Terminalia argentea* (13.4%; 86.13%; 0.47%), *Enterolobium gummiferum* (14.81%; 84.10%; 1.10%), *Hymenaea stigonocarpa* (12.27%; 87.29%; 0.44%), *Xylopia aromatica* (14.72%; 84.96%; 0.30%), *Tachigali aurea* (15.11%; 84.67%;

0.22%), *Vatairea macrocarpa* (18.61%; 80.56%; 0.83%), *Simarouba versicolor* (14.59%; 85.07%, 0.34%). It is noted that among the seven species studied, all presented volatile materials, above 80%.

As a result of this, fixed carbon and volatile materials are inversely proportional. When wood has a high content of volatile materials, its fixed carbon tends to be lower, as much of the matter is volatilized. On the other hand, woods with lower levels of volatile materials tend to have more fixed carbon, resulting in slower and more prolonged burning, with better quality charcoal production.

Similarly, there is a bond for the fixed carbon content and ash. Fixed carbon is the useful fraction from an energy point of view, while ash content represents the inherent material. With the increase in ash content, it usually reduces the efficiency of burning, as less carbon is available for combustion.

However, the ash content is not directly related to the content of volatile materials, but excess ash can interfere with the release of volatile compounds during burning, especially affecting the combustion process and the quality of the coal produced.

The elemental chemical analysis shows different results according to the works (Silva et al., 2015), the parameters of carbon, hydrogen where they are the main components for energy generation, oxygen contributes negatively according to Ferreira et al. (2021). However, it is worth noting that, among the seven native species of the Cerrado used in this work, as they are native forests, all have height, age and diameters, even different phytosanitary conditions, which for the laboratory analysis of this research, may be a decisive factor to explain the reason for the discrepancy of the results analyzed.

The average carbon content for the seven species studied was close to 48%, that is, carbon, in addition to being essential for wood, represents half of the composition of matter, because it is the main element that makes up the cells of plants, including trees. Cellulose and lignin, for example, are made of carbon chains, and this is what allows wood to be strong, durable with a good rigid structure.

The average hydrogen in native woods is usually between 5% and 6% by mass, but this value can vary depending on the species and environmental factors. According to Coelho Filho (2024), the integration of hydrogen as an energy source for industrial processes presents a promising opportunity for the transition from traditional hydrogen production methods that rely on fossil fuels. After all, hydrogen and carbon are fundamental for generating energy from biomass because they are the main fuel elements present in wood. They directly influence the biomass PCS and energy yield, combustion, gasification and pyrolysis processes. According to Ziviani Fernandes *et al*. (2023), hydrogen reacts with oxygen to form water vapor and release a large amount of "hydrogen-green" energy.

Among all seven species studied, it is worth noting that the species *Terminalia argentea* (45.07%) and *Hymenaea stigonocarpa* (45.28%) showed high carbon rates, which for Trugilho (2012), reports that carbonization is satisfactory where high concentrations of carbon in charcoal indicate an increase in energy density.

The average oxygen level varies between 43% and 45%, being within the limits of this research. However, high oxygen rates pose a problem for power generation, as it results in low PCS rates, in addition to contributing to the emission of O_2 and H_2O. According to studies carried out (Eloy; Silva & Caron 2022) and confirmed by Ferreira et al. (2024) highlighted that the chemical composition of biomass, including oxygen content, directly affects its energy value.

However, the species that obtained high calorific value also showed a good relationship in their chemical and physical composition (basic density, lignin, holocellulose and fixed carbon), as a result, there was an increase in energy yield for the species of *Xylopia aromatica* (4603.25 Kcal/Kg), *Tachigali aurea* (4614.90 Kcal/Kg) and *Vatairea macrocarpa* (4654.21 Kcal/Kg).

The upper calorific value (SCW) of wood from native Brazilian species varies according to the species and cultivation conditions. Studies indicate that coniferous woods have an average PCS of approximately 5,200 Kcal/Kg, while broadwoods, such as the native species observed, have an average PCS of around 4,500 Kcal/Kg (Zaque et al., 2017).

For example, research carried out with five species of wood from the Cerrado of Minas Gerais recorded PCS values ranging from 4,516 Kcal/Kg to 4,989 Kcal/Kg, with an average of 4,763 Kcal/Kg (Vale et al., 2022). These values are in line with the limits stipulated for broadleaves, which range from 3,000 to 5,400 Kcal/Kg (Araújo et al., 2018).

The energy density of native woods from the Brazilian Cerrado can also vary according to the species. The research carried out with 34 native forest species of the Cerrado, found an average energy density of approximately 12.459 Kcal/cm³ (Da Silva; Do Vale, 2018), according to the seven species of this research, an average energy density of 2497.331 Kcal/cm³ was determined. The species *Terminalia argentea* (3180.64 Kcal/cm³), *Hymenaea stigonocarpa* (3136.45 Kcal/cm³) and *Tachigali aurea* (3059.76 Kcal/cm³) showed higher energy density due to the high yield of the basic density of the wood, lignin content and the low ash content.

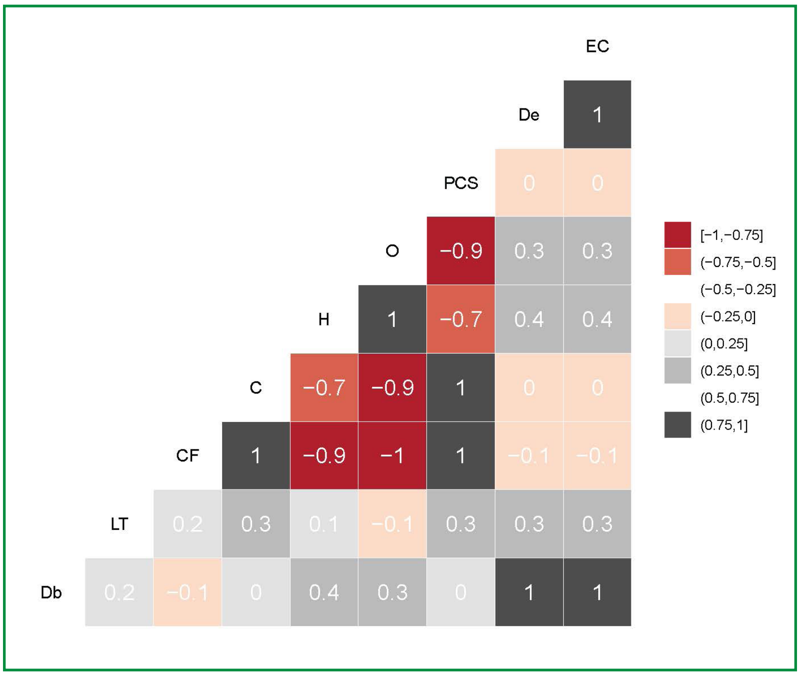
The result of the estimation of the carbon stock in native Cerrado woods of the present study was good, due to the good conditions of basic density, high content of lignin present in the wood that ended up contributing to the increase in the fixed carbon content, but it is known that the carbon stock can vary according to the region and the methodology used. The study published by (Oliveira et al., 2021), used geotechnologies to update the mapping of the carbon volume stock in Cerrado fragments, indicating that the carbon stock in living biomass above ground can vary significantly. However, these variations are influenced by factors such as phytophysiognomy, edaphoclimatic conditions and management practices.

3.2 Wood correlation analysis

In Figure 1 we can observe through Pearson's correlation the wood parameters for the seven species studied, and there are equivalences considered high when compared with proportional correlations and low correlations when compared with indirectly proportional correlations.

The graph is a correlation matrix, representing the strength and direction of the relationship between different variables. Each cell shows the correlation coefficient, ranging from -1 to 1: strong and negative, strong and positive, and moderate to weak.

Figure 1 – Correlation between the parameters analyzed for the wood of seven species from the Cerrado



Source: Authors (2025)

Where: Db - basic density; LT - total lignin; CF - fixed carbon; C - carbon; H - hydrogen; O - oxygen; PCS - higher calorific value; De-energy density; EC - carbon stock; Species analysed: *Terminalia argentea* (Garroteiro), *Enterolobium gummiferum* (Tamboril), *Hymenaea stigonocarpa* (Jatobá-do-Cerrado), *Xylopia aromatica* (Pindaíba), *Tachigali aurea* (Cachamorra), *Vatairea macrocarpa* (Angelim-amargoso), *Simarouba versicolor* (Mata-menino).

Colors reflect the intensity and direction of correlations: darker shades represent stronger correlations (positive or negative), while lighter shades indicate weaker or near-zero correlations. In this way, these correlations help to understand how one variable can affect the other and indicate any that may present significant relationships, positive or negative, between them.

In the first analysis, there is a strong negative correlation between SSP and O (-0.9), C and O (-0.9), and between H and FC (-0.9). This indicates that, as one of these variables increases, the other tends to decrease significantly. For FC and O they also have a correlation of (-1), showing a complete inverse relationship between these variables.

Then, it is possible to observe in the graph the strong and positive correlations, where the variable of CE has correlation (1) with DE, indicating a perfect positive relationship. For Db and CF, on the other hand, they have a strong positive correlation with themselves (1), that is, the higher the basic density of the wood, the higher the fixed carbon content tends to be.

Lignin, in its chemical structure, is composed of phenylpropanoid units – guaiacyl, syringyl and p-hydroxyphenyl, rich in closed bonds between carbon, hydrogen and oxygen atoms (Barbosa et al., 2008; Ramos et al., 2024). Therefore, this structural complexity hinders thermal degradation and contributes to greater carbon fixation in charcoal.

In view of this, there are moderate to weak correlations and indicate that LT and O have a moderate positive correlation (0.3), suggesting a direct relationship, but not very strong. However, Db and LT have a weak correlation (0.2), which indicates a very slight relationship between these variables. Colors reflect the intensity and direction of correlations: darker shades represent stronger correlations (positive or negative), while lighter shades indicate weaker or near-zero correlations. In this way, these correlations help to understand how one variable can affect the other and indicate any that may present significant relationships, positive or negative, between them.

The correlations of PCS with DE, FC and C were relatively positive close to 1. The PCS and DE of wood can be influenced by several factors that, in this specific case, resulted in a correlation close to zero or null in fact. This indicates that there is no direct correlation between these two variables due to the type of chemical composition, moisture content, basic density, and even ash content.

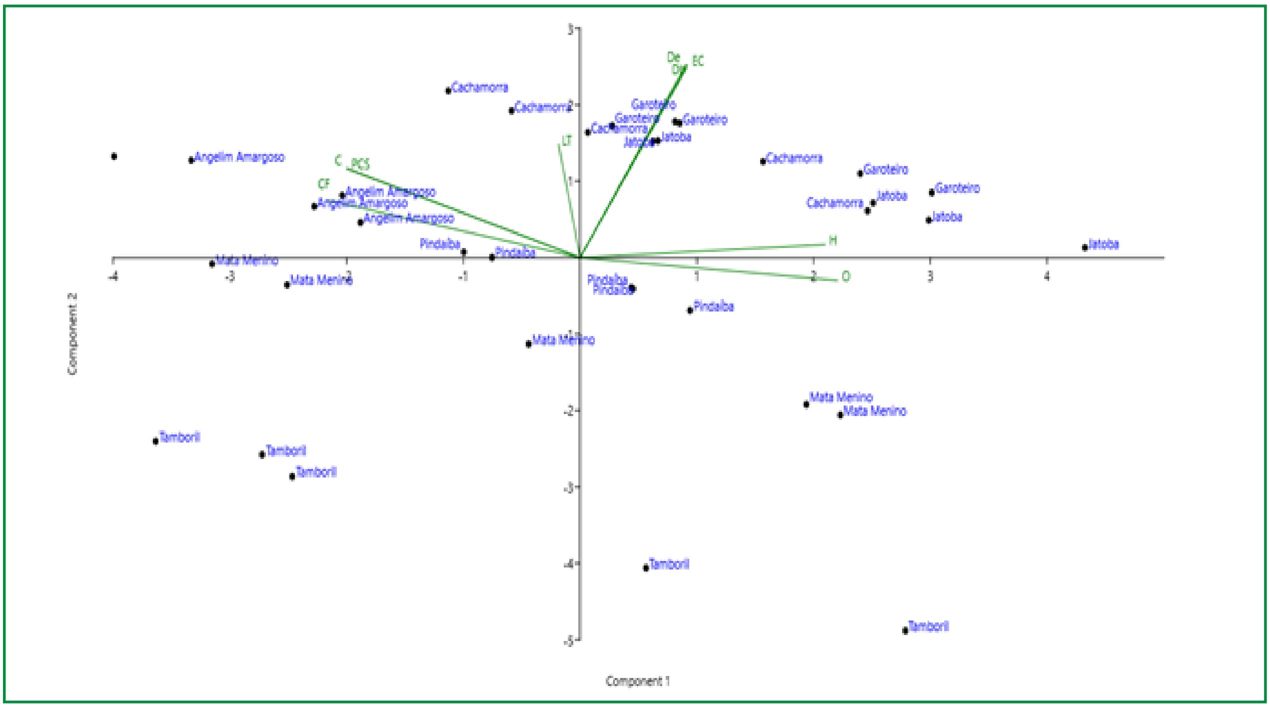
Under these factors, and others, they can counteract the influences that PCS and density exert on ED, resulting in a zero correlation. The same result was observed in the works of Soares et al. (2014) and in other studies in the area. For PCS and CF, their bond is positive (1), as the amount of fixed carbon contributes to a longer and more efficient combustion (Takahashi et al., 2021).

The works done by Resende et al. (2021) and Loureiro et al. (2021) state that the higher the CF and the lower the MV and Cz contents, the higher their PCS, because burning occurs more slowly and efficiently. Therefore, the relationship between PCS and C tends to have a positive correlation (1), which is why the greater the amount of carbon present in the wood, the greater the energy available.

3.3 Principal Component Analysis (PCA) of Wood

Figure 2 shows the biplot of the Principal Components Analysis (PCA) for variables related to the characteristics of different wood species. In it, arrows represent the variables and the points represent the wood species. Based on this, the key aspects identified were: Component 1 and Component 2.

Figure 2 – Grouping of species according to Principal Component Analysis (PCA) of wood



Source: Authors (2025)

In where: Db = basic density; LT = total lignin; CF = fixed carbon; C = carbon; H = hydrogen; O = oxygen; PCS = higher calorific value; De = energy density; EC = carbon stock; Species analysed: *Terminalia argentea* (Garroteiro), *Enterolobium gummiferum* (Tamboril), *Hymenaea stigonocarpa* (Jatobá-do-Cerrado), *Xylopia aromatica* (Pindaíba), *Tachigali aurea* (Cachamorra), *Vatairea macrocarpa* (Angelim-amargoso), *Simarouba versicolor* (Mata-menino).

The PCA made it possible to identify the directions of greatest variation in the data, represented by Components 1 and 2. Each component is formed by a linear combination of the original variables, contributing to explaining the overall variability. The length and orientation of the arrows indicate each variable's influence, with longer arrows farther from the center reflecting a greater impact in that component's direction.

For Component 1, the variables that contributed most were Basic Density (Db), Carbon (C), and Fixed Carbon (CF). Db displayed the longest arrow, suggesting a strong association with this component. Moreover, C and CF formed small angles with each other, indicating a positive correlation and contribution in the same direction.

Component 2 was mainly influenced by Carbon Stock (EC) and Energy Density (DE), while Total Lignin (LT) and Higher Heating Value (PCS) also contributed, though less significantly.

The forest species are distributed across the biplot quadrants according to their characteristics. Species like *Enterolobium gummiferum* and *Simarouba versicolor* appeared in negative quadrants, suggesting that their properties oppose those of variables represented in the positive quadrants. Conversely, *Terminalia argentea* and *Tachigali aurea* are closer to the positive axis of Component 2, indicating an association with variables such as EC and DE. *Vatairea macrocarpa* was positioned in the positive quadrant of both components, reflecting mixed characteristics.

The correlation between variables, such as the proximity of C and CF, confirms their positive relationship, which was previously evidenced by the correlation matrix. Variables forming angles near 90°, such as Oxygen (O) and Basic Density (Db), indicate little to no correlation. Therefore, the biplot proves to be a useful tool for classifying forest species based on their physical, chemical, and energy properties, enabling the grouping of similar species and distinction of those with divergent characteristics.

4 CONCLUSIONS

The results of this study can guide sustainable forest management strategies and encourage the use of native species in energy production. Species with higher basic density, such as *Terminalia argentea* and *Hymenaea stigonocarpa*, demonstrated greater energy potential, while those with lower density, like *Xylopia aromatica* and *Simarouba versicolor*, showed lower efficiency.

The chemical analysis revealed variations in lignin, holocellulose, and total extractive contents among the species, directly influencing their physical, chemical, and energy characteristics. Species with high lignin content, such as *Tachigali aurea*, were more suitable for solid biofuel production, improving carbonization efficiency and charcoal quality. Moreover, the relationship between holocellulose and lignin affects energy conversion efficiency, serving as a crucial selection criterion for energy purposes.

Another relevant factor was the extractive content, which can impact wood calorific value, especially when these compounds are phenolic in nature. Species such as *Terminalia argentea* and *Hymenaea stigonocarpa*, with high fixed carbon content, showed greater potential for energy generation. In contrast, species like *Enterolobium gummiferum* and *Vatairea macrocarpa*, with high ash content, may have reduced combustion efficiency due to lower carbon availability for exothermic reactions.

The PCA classified the species based on their properties, highlighting similarities and differences among them. The study reinforces the importance of properly selecting species for energy applications, showing that woods with high basic density and high levels of lignin and fixed carbon perform better in thermal energy generation.

Therefore, the valorization and proper reuse of Cerrado species can contribute to the sustainability of the energy matrix by reducing dependence on exotic species such as *Pinus* and *Eucalyptus*, as well as on fossil fuels. It is essential to further explore the potential of native Cerrado species, driving innovation, strengthening research, and promoting sustainability in the Brazilian energy matrix.

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REFERENCES

ABDOU ALIO, M. et al. Hydrolysis and fermentation steps of a pretreated sawmill mixed feedstock for bioethanol production in a wood biorefinery, **Bioresource Technology**, vol. 310, 2020, 123412, ISSN: 0960-8524. DOI: https://doi.org/10.1016/j.biortech.2020.123412.

AMERICAN SOCIETY FOR TESTING AND MATERIALS - **ASTM. D-2395**: standard test methods for specific gravity of wood and wood-based materials. Philadelphia, p.8, 2022.

ARAÚJO, A. C. C. de; COSTA, L. J.; BRAGA, P. P. de C.; NETO, R. M. G.; ROCHA, M. F. V.; TRUGILHO, P. F. Propriedades energéticas da madeira e do carvão vegetal de *Cenostigma macrophyllum*: subsídios ao uso sustentável. **Pesquisa Florestal Brasileira**, 38. 2018. DOI: https://doi.org/10.4336/2018.pfb.38e201701546.

ARAUJO, H. J. B. de. Caracterização do material madeira. *In:* SEABRA, G. (org.). **Educação ambiental: o desenvolvimento sustentável na economia globalizada.** Ituiutaba, MG: Barlavento, 2020. p. 31-44.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS - **NBR 8112**. Carvão vegetal - análise imediata, Out/1986.

BARBOSA, L. C. A.; MALTHA, C. R. A.; SILVA, V. L.; COLODETTE, J. L. Determinação da relação Siringila/Guaiacila da lignina em madeiras de eucalipto por pirólise acoplada à cromatografia gasosa e espectrometria de massas (PI-CG/EM). **Química Nova**, São Paulo, v. 31, n. 8, p. 2035-2041. 2008.

CHANNIWALA, S.A.; PARIKH, P.P. A Unified Correlation for Estimating HHV of Solid, Liquid and Gaseous Fuels. **Combustível**, 81, 1051-1063, 2002.

COELHO FILHO, E. A. de S. Hidrogênio, energia renovável: sua utilização em ambiente industrial. **Ibero-Americana de Humanidades, Ciências e Educação**, *[S. l.]*, v. 10, n. 6, p. 3939, 2024. DOI: https://doi.org/10.51891/rease.v10i6.14671.

COSTA, L. B. Caracterização das propriedades químicas de três espécies vegetais do bioma Cerrado. **Rev. Sistemática**, v. 14, n. 4, 958–966, 2024. DOI: https://doi.org/10.56238/rcsv14n4-015.

DA SILVA, C. J.; DO VALE, A. T. Modelo para determinação de densidade energética de espécies florestais do Cerrado. **Caatinga**, 2018. DOI: https://doi.org/10.1590/1983-21252018v31n216rc.

DANESH, P.; NIAPARAST, P.; GHORBANNEZHAD, P.; ALI, I. Biochar Production: Recent Developments, Applications, and challenges. **Fuel**, n.337, 2023. DOI: https://doi.org/10.1016/j.fuel.2022.126889.

DE SIQUEIRA, H. F.; PATRÍCIO, E. P. S.; LIMA, M. D. R.; GUIMARÃES JUNIOR, J. B.; OLIVEIRA CARNEIRO, A. de C.; TRUGILHO, P. F.; PROTÁSIO, T. de P. Avaliação de três madeiras nativas do Cerrado goiano visando à utilização energética. **Nativa**, *[S. l.]*, v. 8, n. 5, p. 615–624, 2020. DOI: https://doi.org/10.31413/nativa.v8i5.10338.

DEUS, D. A. DE; ZAÚ, A. S.; MUNIZ, G. I. B. DE; NISGOSKI, S.; ABREU, H. DOS S.; GAMA, D. C. Lignina: uma importante tecnologia química da madeira. **E-Acadêmica**, *[S. l.]*, v. 3, n. 3, p. e7233391, 2022. DOI: https://doi.org/10.52076/eacad-v3i3.391.

ELNISKI A.; DONGRE, P.; BUJANOVIC, B.M. Uso de lignina na melhoria das propriedades de pellets. **Florestas**. v.14, n.10, 2041, 2023. DOI: https://doi.org/10.3390/f14102041.

ELOY, ELDER; SILVA, DIMAS AGOSTINHO da; CARON, BRALIO OTOMAR. Produção e qualidade da biomassa de florestas energéticas no norte do rio grande do sul, brasil. **Floresta**, *[S. l.]*, v. 52, n. 3, p. 457–465, 2022. DOI: https://doi.org/10.5380/rf.v52i3.86799.

EPE -Empresa de Pesquisa Energética (Brasil). **Balanço Energético Nacional (BEN) 2024: Ano base 2023 / Empresa de Pesquisa Energética**. – Rio de Janeiro: EPE, 2024. 292 p.

FERREIRA, S. de O. P. M.; FERREIRA JÚNIOR, J. A. M.; & BRAZ, R. L. Caracterização energética de biomassas agrícolas e florestais no estado de Pernambuco. **Ciência Florestal**, v. 34 n.3, e73324, 2024. DOI: https://doi.org/10.5902/1980509873324.

FERREIRA, V. R. da S.; TAKAHASHI, V. M.; CADEMARTORI, P. H. G. de; CARNEIRO, M. E.; da SILVA, D. A. Qualidade energética de resíduos madeireiros paricá e pinus. **Energia na agricultura**, v. 36, n. 2, p. 230–238, 2021. DOI: https://doi.org/10.17224/EnergAgric.2021v36n2p230-238.

FIGUEIREDO, E. L. de O.; MEDEIROS NETO, P. N. de; RIBEIRO, L. da S.; SIMÃO, K. de L. A. .; BASTOS, P. de M. Potencial energético da madeira de duas espécies de ocorrência no semiárido brasileiro. **RSDV**, 12, 688-700, 2024. DOI: https://doi.org/10.31416/rsdv.v12i2.715.

GOMES JUNIOR, F. G. Aplicação da análise de imagens para avaliação da morfologia interna de sementes. Informativo **ABRATES**, v. 20, n. 3, p. 33-51, 2010.

GOMES, K. B. P. et al. Avaliação da morfologia interna de sementes de *Terminalia argentea* (Combretaceae) pelo teste de raios X. **Ciência Agronômica**, v. 45, n. 4, p. 752-759, out-dez, 2014. Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE.

IBÁ - Indústria Brasileira de Árvores. **Relatório 2024** (80 p.). São Paulo: IBÁ.

IBGE - Instituto Brasileiro de Geografia e Estatística (2004). **Mapa de Biomas**. Disponível em: https://geoftp.ibge.gov.br/informacoes_ambientais/vegetacao/mapas/brasil/vegetacao.pdf.

INSTITUTO DE PESQUISAS TECNOLÓGICAS - **IPT**. Madeira: o que é e como pode ser processada e utilizada. São Paulo: n.36, p.1-189, 1985.

JESUS, M. S., COSTA, L. J., FERREIRA, J. C., FREITAS, F. P., SANTOS, L. C., & ROCHA, M. F. V. Caracterização energética de diferentes espécies de *Eucalyptus*. **Floresta**, v. 47, n. 1, p. 11-16, 2017. DOI: https://doi.org/10.5380/rf.v47i1.48418.

LEPAGE, E. S.; OLIVEIRA, A. M. F.; LELIS, A. T.; LOPEZ, G. A. C.; CHIMELO, J. P.; OLIVEIRA, L. C. S.; CAÑEDO, M. D.; CAVALCANTE, M. S.; IELO, P. K. Y.; ZANOTTO, P. A.; MILANO, S. Manual de preservação de madeiras. São Paulo: **IPT**. 2. ed. 1986. 708p.

LIMA, B.L. de; COLEN, F.; ARANTES, M.D.C.; BALDIN, T.; BARAÚNA, E.E.P.; FERNANDES, L.A.; SILVA, L. dos S. A. (2024). Aproveitamento energético de cascas de pequi na produção de briquetes. **Caderno Pedagógico**. 21, 12, e10513. DOI: https://doi.org/10.54033/cadpedv21n12-107.

LIMA, M. D. R. et al. Variabilidade das densidades básica e energética e estoque de carbono na madeira no fuste de clones de *Eucalyptus*. **Scientia Forestalis**, 48 (128), e3302, 2020. DOI: https://doi.org/10.18671/scifor.v48n128.04.

LONG, H.; GU, J.; JIANG, J.; GUAN, L.; LIN, X.; ZHANG, W.; HU, C. (2023). Mechanically strong and biodegradable holocellulose films prepared from *Camellia oleifera* ***shells.*** **Carbohydrate Polymers**, Volume 299, 120189. DOI: https://doi.org/10.1016/j.carbpol.2022.120189.

LORENZI, H. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas do Brasil. 5. ed. Nova Odessa, SP. **Instituto Plantarum**, 2008. 352 p. v. 1.

LOUREIRO, B. A., ASSIS, M. R., MELO, I. C. N. A., OLIVEIRA, A. F. C. F., & TRUGILHO, P. F. (2021). Rendimento gravimétrico da carbonização e caracterização qualitativa do carvão vegetal em clones de híbridos de *Corymbia* spp para uso industrial. **Ciência Florestal**, 31(1), 214–232. DOI: https://doi.org/10.5902/1980509836120.

MARCHESAN, R.; OLIVEIRA, D. N.; SILVA, R. C.; CARVALHO, L. A.; GOMES, R. T.; ALMEIDA, V. C. Quality of charcoal from three species of the *Eucalyptus* and the *Corymbia citriodora* species planted in the south of Tocantins. **Revista Floresta**, Curitiba, PR, v. 50, n. 3, p. 1643 -1652, 2020. DOI: https://doi.org/10.5380/rf.v50i3.65303.

MEDEIROS, B. L. M. A.; GUIMARÃES JUNIOR, J. B. G.; RIBEIRO, M. X., LISBOA, F. J. N.; GUIMARÃES, I. L.; PROTÁSIO, T. P. (2016). Avaliação das propriedades físicas e químicas da madeira de *Corymbia citriodora* e *Eucalyptus urophylla* x *Eucalyptus grandis* cultivadas no Piauí, Brasil. **Nativa**, 4(6), 403–407. DOI: https://doi.org/10.31413/nativa.v4i6.3730.

MÉNARD, D.; BLASCHEK, L.; KRIECHBAUM, K.; LEE, C.C.; SERK, H.; ZHU, C.; LYUBARTSEV, A.; NUOENDAGULA, BACSIK, Z.; BERGSTRÖM, L.; MATHEW, A.; KAJITA, S.; PESQUET, E. Plant biomechanics and resilience to environmental changes are controlled by specific lignin chemistries in each vascular cell type and morphotype, **The Plant Cell**, v.34, ed. 12, (2022), p. 4877–4896, DOI: https://doi.org/10.1093/plcell/koac284.

OLIVEIRA, I. M. S. de; REIS, A. A. dos; SILVEIRA, E. M. de O.; ACERBI JÚNIOR, F. W.; MELLO, J. M. de. Estoque do potencial produtivo do Cerrado utilizando geotecnologias. **Ciência Florestal**, v. 31, n. 2, p. 766–785, 2021. DOI: https://doi.org/10.5902/1980509838596.

PROTÁSIO, P. T.; COUTO, A. M.; REIS, A. A. dos; TRUGILHO, P. F.; GODINHO, T. P. Potencial siderúrgico e energético do carvão vegetal de clones de *Eucalyptus* spp. aos 42 meses de idade. **PFB**, v. 33, n. 74, p. 137-149, 2013. DOI: https://doi.org/10.4336/2013.pfb.33.74.448.

RAMOS, R. D.; LONGUE JÚNIOR, D.; PEREIRA, G. S.; SILVA, J. V. M. da; Valle, M. L. A.; DIAS JÚNIOR, A. F. Influência da densidade básica e da composição química da madeira para o processo de carbonização. **Ciência Florestal**, v. 34, n. 4, e87722, 2024. DOI: https://doi.org/10.5902/1980509887722.

REIS, G. de M. F.; MARCHESAN, R.; SILVA, M. A.; SARAIVA, K. F.; MORAES, T. P. E. de; FORTES, R. A.; CARVALHO, A. dos G. de; LIMA, V. O. de; SANTOS, A. F. dos. (2025). Durabilidade natural da madeira de *Myracrodruon urundeuva* Fr. All. **Ciência Florestal**, 35, e87970. DOI: https://doi.org/10.5902/1980509887970.

REIS, P. C. M. dos R.; SOUZA, A. L. de; REIS, L. P.; CARVALHO, A. M. M. L.; MAZZEI, L.; REIS, A. R. S.; TORRES, C. M. M. E. Agrupamento de espécies madeireiras da Amazônia com base em propriedades físicas e mecânicas. **Ciência Florestal**, v.29, n.1, p.336–346, 2019. DOI: https://doi.org/10.5902/1980509828114.

RESENDE, D. R.; ARAUJO, E. da S.; LORENÇO, M. S.; ZIDANES, U. L.; BIANCHI, M. L.; TRUGILHO, P. F.; MORI, F. A. (2021). Potencial energético de resíduos do processamento de café combinados com finos de carvão vegetal. **Pesquisa, Sociedade e Desenvolvimento**, 10(15), e326101523012. DOI: https://doi.org/10.33448/rsd-v10i15.23012.

SANTOS, C. P. S., SANTOS, R. C., CARVALHO, A. J. E., CASTRO, R. V. O., COSTA, S. E. L., LOPES, L. I., PAREYN, F. G. C., DIAS JÚNIOR, A. F., TRUGILHO, P. F., CARVALHO, N. F. O., & MAGALHÃES, M. A. (2020). Estoque de energia da madeira em áreas sob manejo florestal no Rio Grande do Norte. **Scientia Forestalis**, 48(126), e3080. DOI: https://doi.org/10.18671/scifor.v48n126.06.

SANTOS, V. B.; *et al.* Energy potential of charcoal. **BioResources**, v.18, n.1, p.1780-1787, 2023. DOI: 10.15376/biores.18.1.1780-1787.

SEPLAN. Atlas do Tocantins: subsídios ao planejamento da gestão territorial. 6. ed. Palmas: **Secretaria do Planejamento e da Modernização da Gestão Pública**, 80 p. 2012.

SILVA, D. A.; MULLER, B. V.; KUIASKI, E. C.; ELOY, E.; BEHLING, A.; COLAÇO, C. M. (2015). Propriedades da madeira de *Eucalyptus benthamii* para produção de energia. **Pesquisa Florestal Brasileira**, 35(84), 481–485. DOI: https://doi.org/10.4336/2015.pfb.35.84.677.

SILVA, J. M.; MORAES, M. L. T.; SEBBENN, A. M. Autocorrelação espacial em populações natural de *Terminalia argentea* Mart et Zucc. no Cerrado de Selvíria, MS. **Scientia Forestalis**, v. 2, n. 66, p. 94-99, 2004.

SILVEIRA, E. A. *et al*. Efeito da severidade da torrefação na recuperação de energia de resíduos de madeira amazônica para sistemas descentralizados de conversão de energia. **Bioenergia de Biomassa**, (2025). DOI: https://doi.org/10.1016/j.biombioe.2024.107515.

SOARES, V.C. *et al.* Correlações entre as propriedades da madeira e do carvão vegetal de híbridos de eucalipto. **Revista Árvore**, Viçosa-MG, v.38, n.3, p.543-549, 2014. DOI: https://doi.org/10.1590/S0100-67622014000300017.

SOLEYMANI, M.; SHOKRPOOR, S.; JAAFARZADEH, N. Um estudo abrangente das propriedades essenciais do *Conocarpus erectus* como um potencial cultura bioenergética. **Int. J. Environ. Sci. Technol**, 2023. DOI: https://doi.org/10.1007/s13762-023-04878-w.

SOUZA, E. S. C. de; HURTADO DE MENDOZA, Z. M. dos S.; BORGES, P. H. de M.; FRANÇA, G. da S. Propriedades químicas de madeiras nativas comerciais. **Multitemas**, v. 21, n. 59, p. 113–126, 2020. DOI: https://doi.org/10.20435/multi.v21i59.2803.

TAKAHASHI, V. M.; FERREIRA, V. R. da S.; CADEMARTORI, P. H. G. de; CARNEIRO, M. E.; SILVA D. A. da. Qualidade energética de resíduos madeireiros paricá e pinus. Energia na agricultura, **Energia na Agricultura**, Botucatu, v. 36, n. 2, p. 230-238, abril-junho, 2021. DOI: http://dx.doi.org/10.17224/EnergAgric.2021v36n2p230-238.

TRUGILHO, P. F. Energia da biomassa florestal. **Lavras**, MG. 2012. 17p. Disponível em: https://www.eucalyptus.com.br/artigos/2012_Energia_Biomassa+Florestal.pdf.

VALE, A. T. do; BRASIL, M. A. M.; LEÃO, A. L. Quantificação e caracterização energética da madeira e casca de espécies do Cerrado. **Ciência Florestal**, v. 12, n. 1, p. 71–80, 2002. DOI: https://doi.org/10.5902/198050981702.

VIEIRA, T. A. S.; ARRIEL, T. G.; ZANUNCIO, A. J. V.; CARVALHO, A. G.; BRANCO-VIEIRA, M.; CARABINEIRO, S. A. C.; TRUGILHO, P. F. (2021). Determinação da composição química de *Eucalyptus* spp. Para produção de celulose celulósica. **Florestas**, 12 (12), Artigo 1649. DOI: https://doi.org/10.3390/f12121649.

VIVIAN, M. A.; NETO, O. R.; DUARTE, G. A.; PAES, S. T. da S.; MOREIRA, L. M.; MODES, K. S.; SILVA JÚNIOR, F. G. da; DOBNER JÚNIOR, M. Podocarpus lambertii wood quality for the production of long fiber pulp. **Revista de Ciências Agroveterinárias**, Lages, v. 23, n. 3, p. 473–482, 2024. DOI: https://doi.org/10.5965/223811712332024473.

WASTOWSKI, AD. Química da madeira.1 ed. Rio de Janeiro: Editora **Interciência**, 2018. 566p.

WELTER, C. A.; ROSO, M. da S.; SCHMITT, E.; SILVA, D. M. da; WACHT, W. L.; MARTINS, V. de M.; RATZLAFF, F. R.; FARIAS, D. T. de; COLDEBELLA, R.; SILVA, G. T. da; PEDRAZZI, C. Propriedades físico-químicas da madeira de *Paulownia tomentosa* Steud. **Ciência Florestal**, v. 34, n. 4, p. e85562, 2024. DOI: https://doi.org/10.5902/1980509885562.

ZANUNCIO, A. J. V.; CARVALHO, A. G.; CARNEIRO, A. C. O.; COLODETTE, J. L.; E ROCHA, M. F. V. (2019). Caracterização química e energética de clones de *Eucalyptus grandis* ***x*** *Eucalyptus urophylla* ***sujeitos a danos causados pelo vento.*** **Revista Árvore**. 43(4), Artigo ID e430401. DOI: https://doi.org/10.1590/1806-90882019000400001.

ZAQUE, L.A., FERREIRA, M.D., CARVALHO, M.T., FERREIRA, A.L., OLIVEIRA, A.C., & PEREIRA, B.L. (2017). Propriedades energéticas da madeira de espécies nativas do Brasil. **In book: Múltiplos Olhares sobre a Biodiversidade** - vol. 5. DOI: 10.29142/mosb5-22.

ZHONG, S.; ZHANG, B.; LIU, C.; ALDEEN, A. S.; MWENYA, S. ZHANG, H. A minireview on catalytic fast co-pyrolysis of lignocellulosic biomass for bio-oil upgrading via enhancing monocyclic aromatics. **Journal of Analytical and Applied Pyrolysis**, vol. 164, 2022.

ZIVIANI FERNANDES, I.M. *et al.* 2023. Hidrogênio verde. Simpósio de Tecnologia Fatec **Jaboticabal**. 3, 1 (dez. 2023), e1313. DOI: https://doi.org/10.52138/sitec.v13i1.301.

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