TreeDimensional Journal, Vol. 12, e024013, 2024
Original Article | **DOI:** doi.org/10.55746/treed.2024.03.013

Evaluation of the Energy use of Pruning *Dipteryx alata* Trees

Rebeca Silva Lisboa[1,*] , Carlos Roberto Sette Junior[1] , Mariana Pires Franco[2]

Abstract
Pruning is equivalent to the removal of whole branches or parts, living or dead, of a plant, to promote balance in the development of the species, therefore, the generation of waste portrays an indispensable and ever-present consequence. The residues derived from pruning come from silvicultural treatments and evidently have great potential to be used in energy generation. Briquetting, in addition to its energy advantage and practicality, collaborates with the mitigation of environmental impacts from encouraging the use of renewable energies to reducing the emission of greenhouse gases, as they are strongly recommended for replacing fossil coal. The main objective of this work was to evaluate the possibility, related to quality and productivity, of the energy use of residual biomass from urban pruning of *Dipteryx alata*, focusing on the production of briquettes, thus encouraging further studies related to native species of the Cerrado and the use of renewable energy. The contents of volatile materials, ash and fixed carbon, higher calorific value, basic and energetic density were determined, and briquettes were produced in a laboratory briquetting machine. The quality of the briquettes was determined through physical-mechanical analyses: apparent density, durability, tensile strength by diametral compression and expansion. The energy density of the biomass had a considerable increase after briquetting, confirming the increase in energy concentration per unit volume in densified materials. Therefore, it was concluded that the use of urban pruning residues of *Dipteryx alata* proved to be suitable for making briquettes to produce renewable and sustainable energy.

Keywords
Urban pruning — Wood density — Biofuel — Briquettes — Baru

[1] *Department of Forest Engineering Federal University of Goiás (UFG), Goiânia/GO, Brasil*
[2] *Institute of Sciences and Engineering – Campus Itapeva, São Paulo State University (UNESP), São Paulo/SP, Brasil*
***Corresponding author**: rebecalisboa1@hotmail.com

1. Introduction

The use of non-renewable resources is a practice associated with the development and population growth, which consequently leads to their depletion, and thus, a constant search for renewable sources, which meet current needs, becomes increasingly necessary (Schneid, 2020). According to the report by the Brazilian Tree Industry (IBÁ), the means of production that meet the domestic supply of energy are divided into 53.9% come from non-renewable sources, 46.1% come from renewable sources of which 8.7% is generated using firewood and charcoal, mainly from planted forests (Indústria Brasileira de Árvores – IBÁ, 2020). Such data make clear the need for continuity and advancement in research aimed at developing sustainable energy production in the country.

The Cerrado occupies approximately 24% of the Brazilian territory and is the second largest biome in Brazil. This region has a great diversity of tree species, including the baru (*Dipteryx alata*) (Resende & Guimarães, 2007). So, this native tree is widely used by the local population for its various applications between food, medicinal and industrial use, landscaping, timber use and recovery of degraded areas, due to its high adaptability, according to Rambo et al. (2020). Although the use of biomass from short-rotation species, such as the Eucalyptus genus in planted forests, has increased in recent years, native species from the Cerrado have been used as wood raw material for energy generation (Simioni, Moreira, Fachinello, Buschinelli & Matsuura, 2017). In view of this, studies where wood energetic potentials of five species native to the Cerrado are evaluated showed favorable results in relation to the high content of extractives and lignin, and low content of holocellulose, according to Marques et al. (2020), this joint assessment of wood constituents is essential for indicating wood energy use.

Despite indications that the use of wood from this species for energy generation is a viable alternative, the lack of studies related to the energy use of *D. alata* biomass residues is still very evident and necessary (Carvalho, 2003). However, *in natura* biomass, despite having a low acquisition cost, may exhibit characteristics that are unattractive for energy purposes, such as low calorific

Received: 2022/11/30 | **Accepted:** 2024/03/01 | **Online published:** 2024/03/14

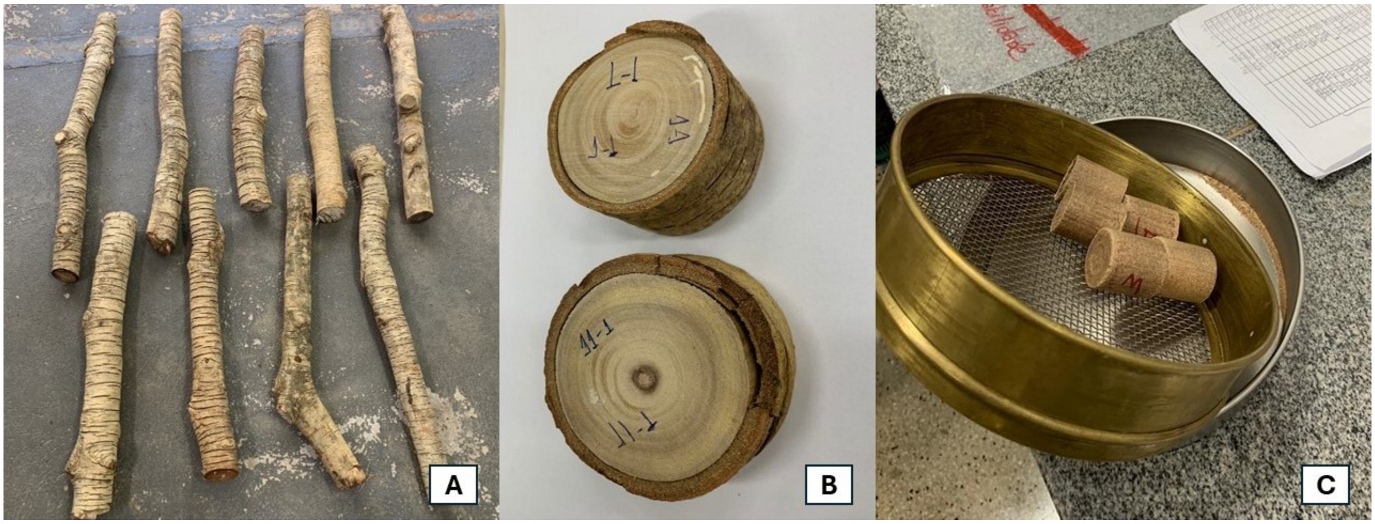

Figure 1. Material used for the analyses; A- *Dipteryx a.* pruning residue; B- Wood sample discs; C- Briquettes produced from the biomass of the processed material.

value, necessitating its transformation into smaller particles, such as briquettes and pellets, aiming for better utilization and greater value aggregation to the final product (Sette et al., 2020; Dulys-Nusbaum, Klammer & Swinton, 2019).

Pruning is equivalent to removing whole branches or parts, living or dead, from a plant. The purpose of this action is to promote balance in the development of species; therefore, the generation of waste portrays an indispensable and ever-present consequence. Therefore, according to the Panorama of Solid Waste in Brazil (Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais – ABRELPE, 2020), organic matter occupies 45.3% of the total waste generated throughout Brazil. In view of this, a clear potential for the use of pruning residues for energy purposes is clear, since Art. 3, item VII of Law No. 12,305, of August 2, 2010, emphasizes that energy use is one of the possible appropriate destinations for solid waste. Evidently, residues derived from forest harvesting have great potential to be used in energy generation, according to Sette et al. (2020), although the residues from pruning, which were used in this work, do not originate from this harvest, they come from silvicultural treatments and are considered biomass (Jasiczek & Kwaśniewski, 2020). It is essential to highlight that, in addition to the energy advantage and its practicality, briquetting collaborates with the mitigation of environmental impacts from encouraging the use of renewable energies to reducing the emission of greenhouse gases (Jasiczek & Kwaśniewski, 2020), also have a potential for replacing fossil coal, contributing to the country's economy (Gustavsson, Haus, Ortiz, Sathre & Le Truong, 2015).

Therefore, this work aims to assess the feasibility, related to quality and productivity, of using the pruning of *Dipteryx alata*, with the goal of proposing a technical solution for the use of residues for energy purposes, as well as bringing innovations regarding native species of the Cerrado to the technical-scientific community.

2. Material and Methods

2.1 Selection of Pruning, Collection and Preparation of Samples

The selected samples were those with a minimum diameter of 6 cm and a maximum of 11 cm; the shell of the samples was maintained. After selecting the prunings, 10 random samples were taken in the form of discs, of this new pile that will be formed for the analyzes (Figure 1).

2.2 Characterization of Biomass

The chemical characterization of the biomass of *Dipteryx alata* residues was carried out in the material at 60 mesh as prescribed in NBR 8112 of ABNT (1986) and the material preparation conditions were applied: the ash, volatile materials, and fixed carbon according to ABNT NBR 8112 (1986).

Bulk density (BUD) was determined according to ABNT NBR 6922 (1981), using the relationship between the mass of biomass and the known volume of a container.

The higher heating value (HHV) was obtained using a calorimeter according to ABNT NBR 8633 standard (1984). Energy density (ED) was calculated from the product of PCS and bulk density.

2.3 Production of Briquettes

The compaction of biomass (production of briquettes) was carried out in a laboratory briquette machine with a pressure of 140 kgf cm-2, compaction time of 5 minutes and cooling for 10 minutes with forced ventilation, at a temperature of 120℃. A standard amount of biomass was used to produce each briquette, 40 g of residue, and the samples were previously dried in an oven at 103℃ and later adjusted to 10% humidity (Figure 1).

The apparent density of the briquettes was determined by means of the volume of the briquette, using a caliper, and the mass, measured on a scale with a precision of 0.001 grams. With the height and diameter measurements of each treatment, the individual volume was obtained (Equation 1) to be used in the apparent density calculation (Equation 2).

$$V = \frac{\pi}{4d^2L}\ , \qquad (1)$$

$$AD = \frac{\mathrm{m}}{V}, \qquad (2)$$

in which: V: Individual volume (cm³); AD: apparent density (g cm⁻³); m is the mass of the sample; d is the sample diameter; L is the sample length.

The volumetric expansion was determined by obtaining its dimensions, height, and diameter. Volume was obtained at two different times: (1) immediately after briquetting and (2) 72 hours after briquetting. This time interval is necessary for the dimensional stabilization of the briquettes. The volumetric expansion was calculated using equation 3.

$$EX = \left[\frac{Vol2 + Vol1}{Vol1}\right] * 100, \qquad (3)$$

in which: EX: volumetric expansion (%); $Vol1$: briquette volume immediately after compaction (cm³); $Vol2$: briquette volume 72 h after compaction (cm³).

The mechanical strength or tensile strength by diametral compression was performed using a universal testing machine EMIC - DL30000, with a load cell of 500 kgf, at a constant speed of 0.3 mm min-1 (de Paula Protásio, Alves, Trugilho, Silva & Baliza, 2011), with the transverse load being applied to the samples. The test was carried out based on an adaptation of the ABNT NBR 7190 standard (1997) for determining the tensile strength by diametral compression in cylindrical samples of concrete and mortar, due to the lack of specific standards for testing briquettes.

The durability or friability of the briquettes was determined by weight loss of the samples, as described by Toscano et al. (2013). Five briquettes were weighed to obtain the initial mass and then placed in a vibrating sieve for 5 minutes at 80 rpm. After this procedure, the briquettes were weighed again, and the final mass was obtained. Friability was calculated using the following equation 4:

$$Dur = 100 - \left[\frac{m_{\text{id}} - m_{\text{fd}}}{m_{\text{id}}}\right] * 100, \qquad (4)$$

in which: Dur: Durability of the briquette in %; m_{id}: Initial mass of the sample (g); m_{fd}: Final mass of the sample (g).

2.4 Data Analysis

The effect of biomass and briquette characteristics on *Dipteryx alata* pruning was evaluated in a completely randomized design. For all variables, averages were obtained with the aim of descriptive comparison between the average values of the analyzes of the treatment in question with species presented in the literature.

3. Results and Discussion

3.1 Immediate Chemical Analysis

The levels of volatile materials, fixed carbon, and ash content in wood are provided through immediate chemical analysis. The fixed carbon content is derived from burning the material in its solid state; the residue from this combustion is the ash, while the volatile materials are those that vaporize into a gaseous form when subjected to high temperatures. These characteristics are crucial when assessing the material's viability as a fuel and also for differentiation purposes (Barrichello & Brito, 1976).

3.1.1 Volatile materials

The percentage of components in the energy material is highlighted through immediate chemical analysis. Concerning volatile materials, the percentage shown was higher than the other parameters, averaging 85.46%. According to Tavares & Santos (2013), the percentage of volatile materials reflects the ease with which the material and fixed carbon burn in each period, being of great importance for combustion. After evaporation, volatile materials mix with oxygen and undergo combustion. Woods with high volatile content burn more quickly (Pereira, Sturion, Higa, Higa & Shimizu, 2000) due to their connection with the material's reactivity and ignition (Klautau, 2008). Similar results were observed by Oliveira (2015), who, when analyzing volatile material levels at different heights in the Eucalyptus clone GFMO-27, obtained an average value of 85.60% across the heights.

3.1.2 Ash Content

The residues resulting from the combustion of organic components and the oxidation of inorganic components

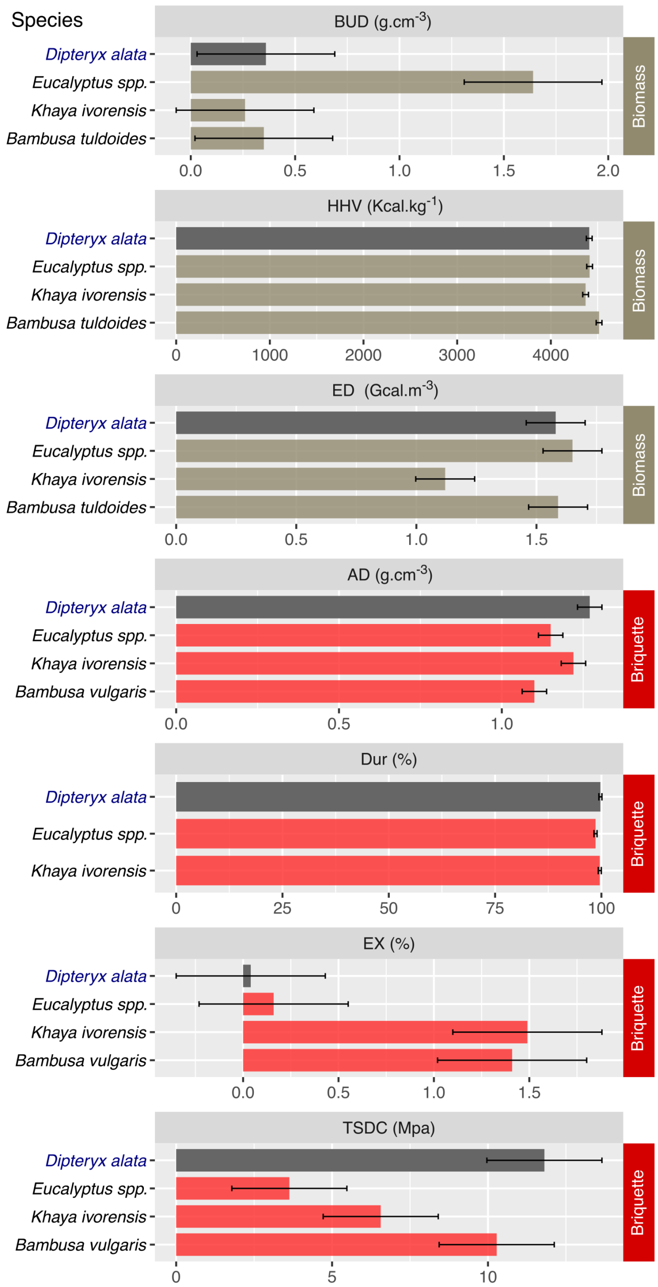

Figure 2. Comparison between the average results of biomass and briquette analyses of the studied species and other species present in the literature. BUD: Bulk density; HHV: Higher Heating Value; ED: Energy density; AD: Apparent density; Dur: Durability; EX: Volumetric Expansion; TSDC: Tensile strength by diametral compression

in wood are characterized as ash content (Vieira, 2012). According to Pereira et al. (2000), ash content can vary depending on the species, the amount of bark present in the material, and other factors such as the presence of sand in the wood. However, for wood to be considered of good quality for energy production, it should have ash content below 3%. In the case of the studied material, the biomass of Dipteryx alata showed an average value of 1.12%. Therefore, in accordance with European and North American standards for solid material production, the found value aligns with the required standards: ash content between 0.5 and 1.5% (Carroll & Finnan, 2012). However, the observed results show higher ash content when compared to literature findings regarding Eucalyptus clones. According to Neves et al. (2011), the authors, in analyzing the energy characteristics of three *Eucalyptus* clones, found ash content ranging from 0.65 to 0.88%.

3.1.3 Fixed Carbon Content

The fixed carbon content present in wood indicates the proportion of the material that was burned in the solid state. This content is directly related to the calorific value because the higher the fixed carbon value of a particular material, the longer the combustion resistance time within the burning device (Barrichello & Brito, 1976). Concerning the biomass of Dipteryx alata, an average fixed carbon content of 13.42% was obtained. The presented value is below the fundamental burning standard for energy production, as recommended by the authors, who suggest fixed carbon levels between 15 and 25%. They assert that fuels with a high index burn more slowly, increasing the resistance time of the energy material when subjected to combustion (Brito & Barrichello, 1982). Other values can be found in the literature, such as the average fixed carbon content presented by Vale et al. (2000), who analyzed 47 woody species from the Cerrado and observed an average fixed carbon content of 20.73%.

3.2 Energetic Characteristics of Biomass

3.2.1 Bulk Density

According to Veiga (2014), wood density is a property of great importance in defining the quality and utilization of the material. It is the most studied characteristic and strongly influences the management of planted forests (de Assis Ribeiro & Zani Filho, 1993). Denser wood has a greater amount of matter in the same volume. The average values obtained for the bulk density (BUD) of *Dipteryx alata* biomass were 0.36 g.cm^{-3}. This value is lower than those found in the literature for *Eucalyptus spp*. (1.64 g.cm^{-3}) (Figure 2) (Souza et al., 2022 ; Moraes, 2017; Sette et al., 2017).

3.2.2 Higher Heating Value

The energy quality of biomass is related to the higher heating value (HHV), in other words, the amount of energy generated in its complete combustion. According to Doat (1997), the higher heating value is characterized when combustion occurs at a constant volume, and the water resulting from combustion is condensed. The average values found for *Dipteryx alata* were 4410 Kcal.kg^{-1} and similar values were found for species of *Eucalyptus spp*. (4414 Kcal.kg^{-1}). The energy density (ED), the product of basic density by the higher heating value, also showed a significant difference when compared to *Khaya ivorensis*, but resembled *Eucalyptus spp*. and *Bambusa tuldoides* (Figure 2) (Souza et al., 2022 ; Moraes, 2017; Sette et al., 2017).

3.3 Energetic and Physical-Mechanical Characteristics of Briquettes

The parameters for assessing briquetting and their influence on the quality of the final product are determined through analyses that aim to present characteristics that directly impact factors such as the apparent density of the briquette, energy density, durability analysis of the briquette, mechanical strength, and finally, the analysis of the expansion of the briquettes. The values of the analysis of *Dipteryx alata* briquettes in comparison to other species in the literature are shown in Figure 2.

3.3.1 Apparent Density

The apparent density (AD) values of the briquette refer to the amount of energy or heat that a specific material with a defined volume can deliver (Quirino & Brito, 1991). Thus, the goal of briquetting any material will always be to concentrate energy potential in a smaller volume compared to the raw material. The briquettes in this study presented an apparent density of 1.27 g.cm^{-3}, higher than the apparent density of briquettes reported in the literature for species such as *Eucalyptus spp*. (1.15 g.cm^{-3}), *Khaya ivorensis* (1.22 g.cm^{-3}), and *Bambusa vulgaris* (1.1 g.cm^{-3}) (Sette et al., 2017; Moraes, Silva, Barbosa, Marques, Silva & Sette Junior, 2019; Júnior, Souza, Lourenço & Interaminense, 2017).

3.3.2 Durability

The durability (Dur) of *Dipteryx alata* briquettes was similar to the durability of *Eucalyptus spp.* and *Khaya ivorensis* found in literature. According to Oliveira et al. (1992), the results of briquette durability directly influence the product quality. Thus, the material evaluated in this study demonstrated to be less friable and of good quality (Sette et al., 2017; Moraes, Silva, Barbosa, Marques, Silva & Sette Junior, 2019; Júnior, Souza, Lourenço & Interaminense, 2017).

3.3.3 Volumetric Expansion

It is normal for briquettes to undergo longitudinal expansion after the briquetting process due to storage conditions, the briquetting process itself, such as temperature and pressure, and the characteristics of the biomass (Silva et al., 2015; Fernandez et al., 2017). The expansion (EX) showed a significant difference when compared to other literature values. *Dipteryx alata* briquettes demonstrated greater dimensional stability precisely because they exhibited very low average expansion values (Sette et al., 2017; Moraes, Silva, Barbosa, Marques, Silva & Sette Junior, 2019; Júnior, Souza, Lourenço & Interaminense, 2017).

3.3.4 Tensile strength by diametral compression

Mechanical strength is a fundamental parameter in evaluating briquette quality as it indicates its stacking ability and resistance to impact during transportation; abrasion, as friction can cause the material to break apart, making its durability value significant (de Paula Protásio, Alves, Trugilho, Silva & Baliza, 2011; Sampaio, Costa & Andrade, 2007). The average values (TSDC) found in *Dipteryx alata* briquettes proved to be very promising, especially when compared to literature values, demonstrating that the material studied in this work qualifies as highly resistant (Sette et al., 2017; Moraes, Silva, Barbosa, Marques, Silva & Sette Junior, 2019; Júnior, Souza, Lourenço & Interaminense, 2017).

4. Conclusions

The energy density had a considerable increase after biomass compaction, confirming the increase in energy concentration per unit volume in densified materials.

Urban pruning residues of *Dipteryx alata* are suitable for making briquettes for energy production.

Although there is still little research on the energy use of urban pruning of species native to the Cerrado, such as Baru, the feasibility of using these residues as biomass in biofuels is evident and this factor is combined with the lower production costs of briquettes.

Acknowledgments

We would like to thank to the Timber Quality and Bioenergy Laboratory (LQMBio) for providing the infrastructure and helping to collect the data used in this research.

References

ABNT – Associação Brasileira De Normas Técnicas. (1981). NBR 6922: Carvão vegetal-ensaios físicos determinação da massa específica (densidade à granel). Rio de Janeiro.

ABNT – Associação Brasileira De Normas Técnicas. (1984). NBR 8633: Carvão vegetal-determinação do poder calorífico. Rio de Janeiro.

ABNT – Associação Brasileira De Normas Técnicas. (1986). NBR 8112: Carvão vegetal-análise imediata. Rio de Janeiro.

ABNT – Associação Brasileira De Normas Técnicas. (1997). NBR 7190: Projeto de estruturas de madeira. Rio de Janeiro.

Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais. (2020). Panorama dos Resíduos Sólidos no Brasil 2020. Brasil.

Barrilechelo, L. E. G., & Brito, J. O. (1976). A madeira das espécies de eucalipto como matéria prima para a indústria de celulose e papel.

Brito, J. D., & Barrichelo, L. E. G. (1982). Aspectos técnicos da utilização da madeira e carvão vegetal como combustíveis. Seminário de abastecimento energético industrial com recursos florestais, 2, 101-137.

Carroll, J. P., & Finnan, J. (2012). Physical and chemical properties of pellets from energy crops and cereal straws. Biosystems Engineering, 112(2), 151-159.

Carvalho, P. E. R. (2003). Baru: taxonomia e nomenclatura (Circular Técnica Embrapa Florestas, No. 104, pp. 1-10). Colombo: Embrapa. Recuperado em, 26.

da Silva, D. A., Yamaji, F. M., de Barros, J. L., da Róz, A. L., & Nakashima, G. T. (2015). Caracterização De Biomassas Para A Briquetagem. Floresta, 45(4).

da Veiga, N. S. (2014). Inferência da densidade da madeira estimada por esclerometria (Doctoral dissertation, [sn]).

de Assis Ribeiro, F., & Zani Filho, J. (1993). Variação da densidade básica da madeira em espécies/procedências de Eucalyptus spp. IPEF, 46, 76-85.

de Paula Protásio, T., Alves, I. C. N., Trugilho, P. F., Silva, V. O., & Baliza, A. E. R. (2011). Compactação de biomassa vegetal visando à produção de biocombustíveis sólidos. Pesquisa Florestal Brasileira, 31(68), 273-273.

de Paula Protásio, T., Trugilho, P. F., de Siqueira, H. F., de Melo, I. C. N. A., Andrade, C. R., & Junior, J. B. G. (2015). Caracterização energética de pellets in natura e torrificados produzidos com madeira residual de Pinus. Pesquisa Florestal Brasileira, 35(84), 435-442.

de Souza, M. M., Silva, D. A., Rochadelli, R., & dos Santos, R. C. (2012). Estimativa de poder calorífico e caracterização para uso energético de resíduos da colheita e do processamento de Pinus taeda. Floresta, 42(2), 325-334.

Dulys-Nusbaum, E., Klammer, S. S., & Swinton, S. M. (2019). How willing are different types of landowner to supply hardwood timber residues for bioenergy?. Biomass and bioenergy, 122, 45-52.

Fernandez, B. O., Gonçalves, B. F., Pereira, A. C. C., Hansted, A. L. S., Pádua, F. A., Da Róz, A. L., & Yamaji, F. M. (2017). Características mecânicas e energéticas de briquetes produzidos a partir de diferentes tipos de biomassa. Revista Virtual de Química, 9(1), 29-38.

Gustavsson, L., Haus, S., Ortiz, C. A., Sathre, R., & Le Truong, N. (2015). Climate effects of bioenergy from forest residues in comparison to fossil energy. Applied Energy, 138, 36-50.

Indústria Brasileira de Árvores. (2020). Relatório anual. Associação Brasileira de Árvores, [s. l.], p. 160, 2020.

Jasiczek, F., & Kwaśniewski, D. (2020). Analysis of production technology of wood briquettes, including costs and distribution. Agricultural Engineering, 24(1), 35-45.

Júnior, D. S., Souza, E. C., Lourenço, Y. B. C. & Interaminense, P. P. B. (2017). Caracterização Física De Briquetes Produzidos A Partir De Resíduos De Bambu (Bambusa Vulgaris) E Serragem De Angelim Vermelho (Dinizia excelsa Ducke).

Klautau, J. V. P. (2008). Análise experimental de uma fornalha a lenha de fluxo cocorrente para secagem de grãos (Doctoral dissertation, Dissertação de mestrado). Universidade Federal do Paraná, Curitiba).

Marques, R. D., da Cunha, T. Q. G., Chagas, M. P., Venturoli, F., Belini, G. B., Yamaji, F. M., & Sette, Jr, C. R. (2020). Wood quality of five species of the

Cerrado for energy purposes.

Moraes, M. D. A. D. (2017). Qualidade e potencial energético da madeira de desbaste de mogno africano.

Moraes, M. D., Silva, M. D., Barbosa, P. V. G., Marques, R., Silva, R. T., & Sette Junior, C. R. (2019). Characterization of Khaya ivorensis (A. Chev) biomass, charcoal and briquettes.

Neves, T. A., de Paula Protásio, T., Couto, A. M., Trugilho, P. F., Silva, V. O., & Vieira, C. M. M. (2011). Avaliação de clones de Eucalyptus em diferentes locais visando à produção de carvão vegetal. Pesquisa Florestal Brasileira, 31(68), 319-319.

Oliveira, D. C. B. D. (2015). Análise física e química da madeira de clone de eucalipto GFMO-27 (Bachelor's thesis, Universidade Tecnológica Federal do Paraná).

Pereira, J. C. D., Sturion, J. A., Higa, A. R., Higa, R. C. V., & Shimizu, J. Y. (2000). Características da madeira de algumas espécies de eucalipto plantadas no Brasil.

Quirino, W. F., Pinha, I. V. D. O., Moreira, A. C. D. O., Souza, F. D., & Tomazello Filho, M. (2012). Densitometria de raios x na análise da qualidade de briquetes de resíduos de madeira. Scientia Forestalis, 40(96), 525-536.

Rambo, M. K., Rambo, M. C., Melo, P. M., Oliveira, N. M. L. D., Nemet, Y. K., Scapin, E., ... & Bertuol, D. A. (2020). Sustainability of biorefinery processes based on Baru biomass waste. Journal of the Brazilian Chemical Society, 31, 273-279.

Resende, M. D. L. F., & Guimarães, L. D. L. (2007). Inventários da biodiversidade do bioma Cerrado: biogeografia de plantas. Rio de Janeiro: IBGE.

Sampaio, J. A., Costa, L. S. N., Andrade, M. C. (2007). Ensaios contínuos de briquetagem em bancada e piloto. In: Tratamento de Minérios: práticas laboratoriais. Rio de Janeiro: CETEM/MCTI, p.379-390.

Schneid, E. (2020). Uso de serragem de diferentes espécies florestais no processo de compactação. Advances in Forestry Science, 7(4), 1203-1212.

Sette Jr, C. R., de Moraes, M. D. A., Coneglian, A., Ribeiro, R. M., Hansted, A. L. S., & Yamaji, F. M. (2020). Forest harvest byproducts: use of waste as energy. Waste Management, 114, 196-201.

Sette, C., Wilk, W., Gondim, J. F. V., da Cunha, T. Q. G., Fonseca, P. A., Marques, R. D., da Silva, M. F., Coneglian, (2017) A. Caracterização da biomassa e qualidade de briquetes produzidos a partir de resíduos de sementes agrícolas e madeira de eucalipto. In: Congresso Brasileiro de Ciência e Tecnologia da Madeira, 3., Florianópolis.

Simioni, F. J., Moreira, J. M. M. Á. P., Fachinello, A. L., Buschinelli, C. C. D. A., & Matsuura, M. I. D. S. F. (2017). Evolução E Concentração Da Produção De Lenha E Carvão Vege-Tal Da Silvicultura No Brasil. Ciência Florestal, 27, 731-742.

Souza, C. D. O., Arantes, M. D. C., Pinto, J. D. A., Silva, J. G. M. D., Carneiro, M. F., Lima, A. C. B. D., & Passos, R. R. (2022). Qualidade dos resíduos madeireiros de mogno-africano e eucalipto para briquetagem. Ciência Florestal, 32, 637-652.

Tavares, S. R. L., & Santos, T. E. (2013). Use of different sources of biomass plant for the production of solid biofuel. Holos, 5, 80-97.

Toscano, G., Riva, G., Pedretti, E. F., Corinaldesi, F., Mengarelli, C., & Duca, D. (2013). Investigation on wood pellet quality and relationship between ash content and the most important chemical elements. Biomass and Bioenergy, 56, 317-322.

Vale, A. (2000). Caracterização da biomassa lenhosa de um cerrado sensu stricto da região de Brasília para o uso energético. 2000. 111p (Doctoral dissertation, Tese (Doutorado). Universidade Estadual Paulista, Botucatu-São Paulo).

Vieira, A. C. (2012). Caracterização da biomassa proveniente de resíduos agrícolas. Universidade Estadual do Oeste do Paraná.

Author Statements

- ✓ No conflicts of interest were declared.
- ✓ All existing funding sources were acknowledged.
- ✓
- ✓ There is no evidence of plagiarism in this article.