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**PRODUCTION OF BRIQUETTES FROM EUCALYPTUS SP. SAWDUST
USING A LIGNOCELLULOSIC RESIDUE FROM 2G ETHANOL
PRODUCTION AS A BINDER**

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Abstract. *The use of the briquetting method consists of compacting biomass with characteristics that are not industrially attractive, as a result, high-density and uniform products such as pellets and briquettes are generated. In Brazil, the main species planted for industrial use is eucalyptus, as a result of the industrial process, various residues are generated, including sawdust. In this work, we used eucalyptus sawdust from a sawmill to produce briquettes, and lignocellulosic residue generated in the production of second-generation ethanol was used as a binder. The results indicate that the use of lignocellulosic waste as a binder has the potential to provide improvements in mechanical strength, density and energy properties. The highest density found was for the use of 20% of the lignocellulosic residue of 984 kg m⁻³. And the highest mechanical resistance was 1257 MPa for the eucalyptus briquette with 20% of the lignocellulosic residue.*

Keywords: *Biomass, briquettes, lignocellulosic residue*

1. INTRODUCTION

Brazil has favorable elements for ethanol production, such as advanced production technology, potential leadership in energy agriculture, and a biofuel market that does not compromise deforested areas or reduce food production. Moreover, the country presents a diversity of raw materials in different biomes (Pacheco, 2011). These factors contribute to Brazil's global prominence as the second-largest ethanol producer, representing 27% of the world's volume in 2021 (RFA, 2023).

Second-generation ethanol (E2G), also known as lignocellulosic ethanol, is obtained from agricultural and forest crop residues. Additionally, by-products generated in the production of first-generation ethanol, such as sugarcane bagasse can be used. In the Brazilian context, E2G has significant advantages due to the abundance of available biomass, and its production does not require the expansion of cultivated areas. Therefore, there is a promising perspective regarding the potential to produce this fuel (De Almeida Lima, 2019).

In this way, with the production of E2G will be generated a significative quantity of lignocellulosic residue. The literature presents scarce studies about the use of lignocellulosic residue, indicating that research is still in its early stages. Some studies have explored pyrolysis to utilize these residues (Sandes et al., 2021). Additionally, they have been investigated as soil amendments, showing potential for application (Godoi et al., 2020). Another promising application is using these lignocellulosic residues as binders in the production of mechanically densified products, such as pellets (De Almeida Moreira, 2021). Specifically, the lignocellulosic residue from second-generation ethanol production has shown positive results as a binder in pellet production.

Mechanical densification is an approach that aims to add value to biomass by producing a product with high bulk density, uniform shape, and ease of handling. This technique involves applying mechanical force to promote particle bonding, resulting in various benefits such as reduced transportation and storage costs, improved combustion, and increased efficiency in fuel feeding to the boiler. Through mechanical densification, the initial bulk density of biomass can be increased from 50-200 kg/m³ to 500-1400 kg/m³ (Kaliyan and Vance Morey, 2009; Tumuluru et al., 2011).

One way to improve the results of mechanical densification is the use of binders, which are used in the formation of briquettes due to their ability to provide better mechanical properties. The literature presents some studies with the use of different types of binders that point out that the type and concentration of the binder play a fundamental role in the physical characteristics of the formed briquette. Among the binders used are cassava starch (Aransiola et al., 2019; Lubwama and Yiga, 2018), cassava wastewater (Yank et al., 2016); bentonite clay (Lubwama and Yiga, 2018), natural (lignocellulosic) binders (Afra et al., 2021) and molasses (Manyuchi et al., 2019).

We proposed the investigation of lignocellulosic residue from the hydrolysis of sugarcane bagasse during the production of second-generation ethanol as a binder in the production of eucalyptus sawdust briquettes. Specifically, eucalyptus wood is the main species planted in reforestation areas in the Brazilian scenario and supports a productive chain of pulp and paper production, sawmills, and furniture manufacturing. For validation of the binder, tests related to mechanical and physical properties were carried out to verify if the product has the capacity to be transported and stored.

2. MATERIALS AND METHODS

2.1 Materials

The eucalyptus sawdust was obtained from the Carbon Mad sawmill located near the city of Itapeva-SP, Brazil. Drying was carried out in an oven and subsequently the selection of particles using sieves to obtain particles smaller than 850 μm (Figure 1). The lignocellulosic residue was obtained from a second-generation ethanol production industry using sugarcane bagasse, in this study the residue used belongs to the solid part resulting from the hydrolysis process of sugarcane bagasse, For the study, the lignocellulosic residue was ground in a Willey-type mill to obtain particles smaller than 100 μm . Figure 1 shows images referring to eucalyptus sawdust and lignocellulosic waste.

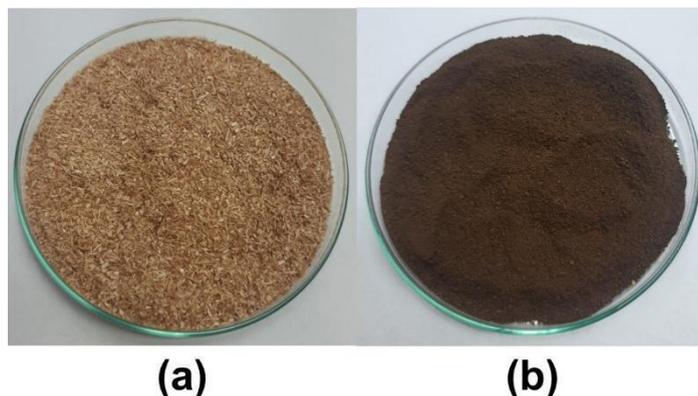


Figure 1. Materials (a) Eucalyptus sawdust; (b) Lignocellulosic residue from 2G ethanol.

2.2 Characterization techniques

Proximal analysis was performed according to ASTM E 871-82 (2013) standards for volatile content, ASTM E 1755-01 (2015) for ash content and for fixed carbon content ASTM D 3175-11 (2011). To determine the higher heating valuer of eucalyptus sawdust, lignocellulosic residue and their blends, an IKA C 5000 bomb calorimeter was used, and the procedures followed the ASTM D 5865 (2013) standard. To determine the mechanical resistance of the briquettes, a universal machine EMIC-DL30000 was used, with a load cell of 500 kgf and a speed of 3 mm min⁻¹, performing compression in the diametrical direction until the rupture of the tension load.

2.3 Production of briquettes

For the production of briquettes, a stainless-steel mold (Fig. 2a) with 3.50 cm in diameter and 16.0 cm in height and a Marconi-MA 098 hydraulic press (Fig. 2b) were used. The dry biomasses were conditioned to a moisture content of 15% on a mass basis for the production of briquettes. The compression pressure used was 128 MPa during 5 min at room temperature. For each treatment, 20.0 of eucalyptus sawdust was added to the mold with increments of different proportions of lignocellulosic residue in mass/mass. The proportions of 5, 10, 15 and 20% addition of lignocellulosic residue were used. For comparative purposes, briquettes were produced with 100% eucalyptus sawdust.

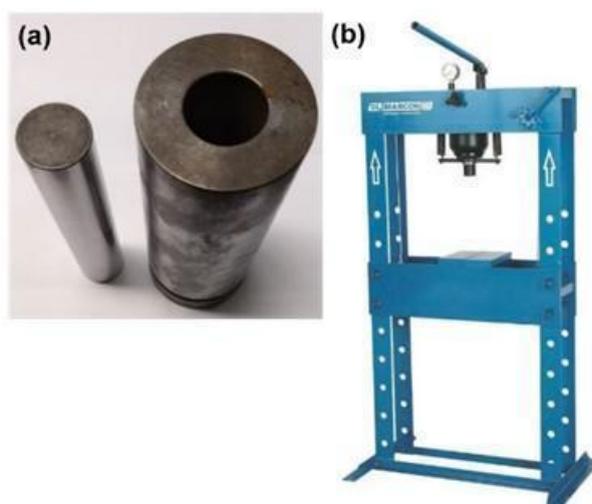


Figure 2. Mechanical densification bench (a) briquette mold; (b) hydraulic press.

3. RESULTS AND DISCUSSION

3.1 Materials characterization

Table 1 shows the results of the proximal analysis and higher heating values, along with some works founded in the literature for eucalyptus sawdust and lignocellulosic residue used as binder. The results of ash, volatile materials fixed carbon, and ash obtained in this work were consistent with those founded in the literature for eucalyptus biomass and lignocellulosic residue binder. The binder showed a high ash content of 5.80%, this is a relevant factor for determining the amount of lignocellulosic residue that is plausible to be added in the production of briquettes, since high ash contents contribute to the reduction of the HHV by not participate in the combustion process and generate residues in the burning boiler, making cleaning more frequent. The high content of volatiles presented by eucalyptus contributes to starting the ignition of the briquettes. Regarding the higher heating value, the lignocellulosic residue presented a higher value than that of eucalyptus sawdust, with this, its greater addition in the production of briquettes causes the final product to generate more energy when burned.

Property *dry basis	In this work		Sette Jr, (2018a)	Araújo et al., (2016)	De Almeida Moreira, (2021)
	Eucalyptus sp.	Lignocellulosic residue from 2G ethanol	Eucalyptus urograndis	Eucalyptus spp.	Lignocellulosic residue from 2G ethanol
*Volatile matter (%)	84,45	68,78	83,01	86,13	69,85
*Fixed carbon (%)	14,76	25,41	16,7	13,05	24,30
*Ash (%)	0,79	5,80	0,3	0,82	5,85
*HHV (MJ/kg)	18,81	21,59	19,485	18,56	21,85

Table 1. Proximal analysis of eucalyptus sawdust and lignocellulosic residue.

3.2 Characterization of briquettes

Figure 2 shows the briquettes after testing the tensile strength by diametral compression of eucalyptus sawdust using lignocellulosic residue in the proportion of 5% (a) and in the proportion of 20% (b) in mass/mass.

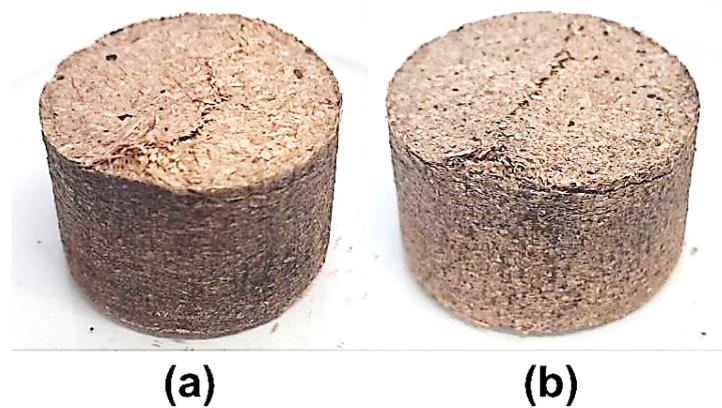


Figure 2. Briquettes (a) Eucalyptus sawdust with 5% lignocellulosic residue; (b) Eucalyptus sawdust with 20% lignocellulosic residue.

Figure 3 shows the result of the compressive strength of the briquettes obtained by the diametral tensile compression test. The mean mechanical strength for pure eucalyptus briquettes and with 20% of the binder were 0.60 and 1.12 MPa, respectively. Figure 4 shows that there is a positive linear regression relationship between the increase in the addition of lignocellulosic residue and the compressive strength of briquettes. This indicates that the addition of lignocellulosic residue provides an improvement in the bonds between particles of eucalyptus sawdust, an effect that can be explained by having a high lignin content resulting from the process of sugarcane bagasse in the production of 2G ethanol (Carvalho et al., 2020).

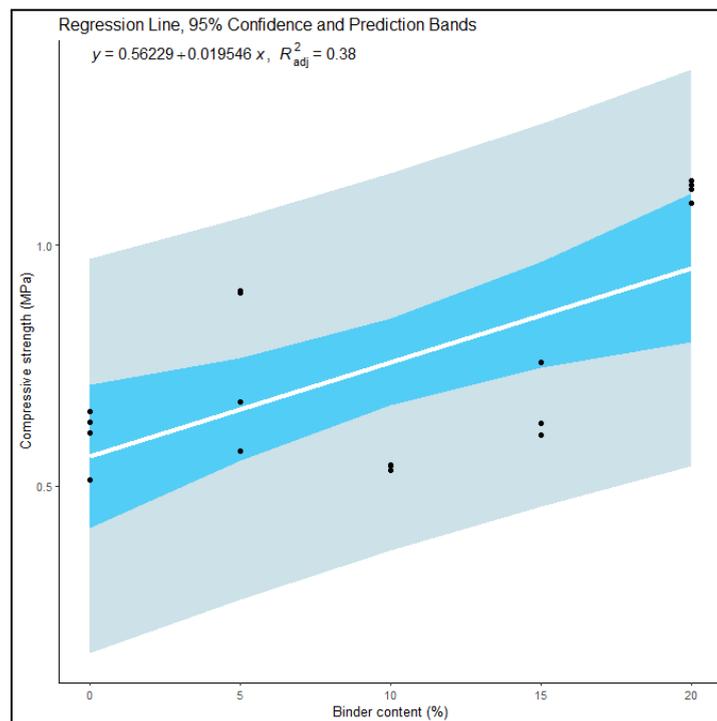


Figure 3. Compressive strength from briquettes.

Silva et al. (2017) obtained compressive strength values for briquettes made with Eucalyptus sp. with moisture contents of 10, 12 and 15%, respectively, 1.06, 1.12 and 0.91 MPa, these values are consistent with this work when lignocellulosic residue is added. This superiority in compressive strength may be due to the particle size range used by the authors which was in the dimension of 500-850 μm , while in this work the dimension was 250-850 μm . The use of very fine particles causes a reduction in compressive strength and an increase in density (Bello and Onilude, 2021; Furtado et al, 2010). However, there are works that point out that different mixed particle sizes can provide improvements in interparticle bonds during the compaction process and generate good quality products (Missagia et al., 2011).

Figure 4 shows the apparent density of the briquettes. Regarding apparent density, there was an increase according to the quantity of lignocellulosic residue added. This increase follows a first-order linear behavior. Moreover, the particle size of lignocellulosic residue, less than 100 μm, could have influenced on apparent density. According to Križan et al., (2015) the reduction in particle size positively influences the increase in briquette apparent density. Sette Jr et al., (2018) obtained an apparent density value of briquettes from eucalyptus in the range of 1310 - 1340 kg m⁻³. These values are higher than obtained in this work. The difference could be explained due to the use of heating temperature. Sette Jr et al., (2018) have considered a heating temperature of 120°C during the briquetting process. There are studies that indicate that the temperature in the process contributes to that the natural binders present in the biomass, such as lignin during the glass transition process, act more efficiently and provide good union between the particles of the process (Kaliyan and Vance Morey, 2009).

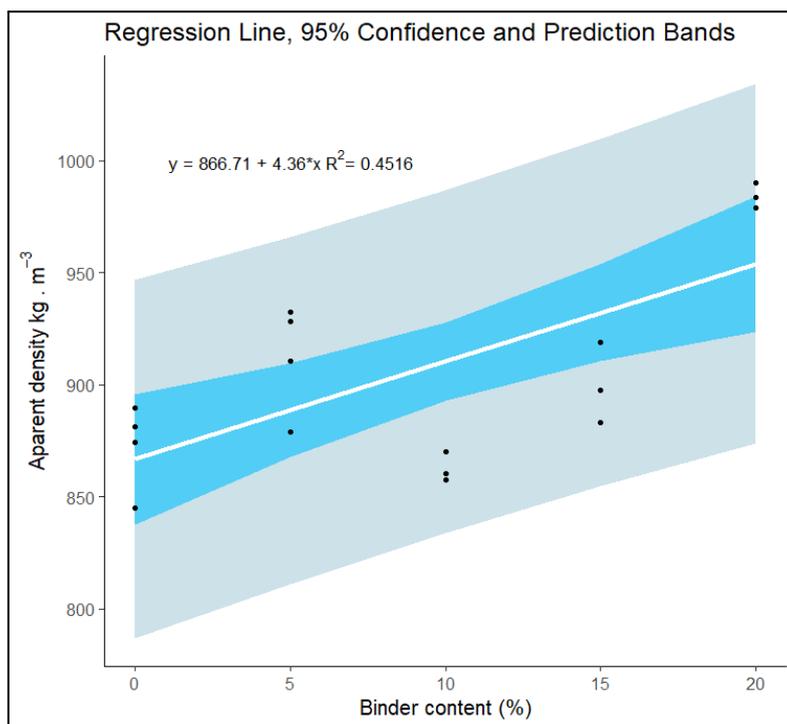


Figure 4. Apparent density of briquettes.

3.3 Energetic properties of briquettes

Table 1 shows the higher heating value and energy density of briquettes. The highest HHV and energy density were obtained with the highest lignocellulosic residue content (20%), corresponding to 19635 MJ/kg and 19.32 GJ/m³, respectively. The lignocellulosic residue has a higher carbon content which results in a greater amount of energy that the material will release during combustion (HHV) and, consequently, the greater addition of the binder to the briquette provides a positive effect energetic effect. Sette Jr et al., (2020b) studied the production of briquettes from Eucalyptus urograndis and Acacia mangium residues and obtained energy densities of 18,168 and 18,197 MJ m⁻³, respectively. Values close to those founded in this work, the difference presented was for the density of the briquettes, for Acacia mangium and eucalyptus urograndis they were 1155 and 1174 kg m⁻³, respectively. The difference may have occurred due to the pressure exerted at 140 MPa, in addition, compaction was carried out using temperature, which facilitates better particle bonding, eliminating voids and increasing apparent density. However, the use of temperature during the briquetting process generates greater energy expenditure for the process.

Briquettes	Eucalyptus 5% LR	Eucalyptus 5% LR	Eucalyptus 10% LR	Eucalyptus 15% LR	Eucalyptus 20% LR
HHV (MJ/kg)	18.812	18.974	19.062	19.556	19635
Energy Density (GJ/m ³)	16,42	17,32	16,44	17,6	19,32

Table 2. Energetic properties of briquettes.

4. CONCLUSIONS

The lignocellulosic residue from the production of 2G ethanol has demonstrated that it can be used as a binder in the production of briquettes. The increase the quantity of lignocellulosic residue provides an increase in the compressive strength and apparent density of eucalyptus-based briquettes, demonstrating a positive linear correlation. The addition of lignocellulosic waste in the production of eucalyptus sawdust briquettes causes an increase in energy density. In this work, it was not necessary to consider a heating temperature during production of briquettes, this condition can reduce the production cost of the briquettes.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

- Afra, E., Abyaz, A., and Saraeyan, A., 2021, The production of bagasse biofuel briquettes and the evaluation of natural binders (LNFC, NFC, and lignin) effects on their technical parameters, *Journal of Cleaner Production*, Vol. 278, pp. 123543.
- Aransiola, E. F., Oyewusi, T. F., Osunbitan, J. A., and Ogunjimi, L. A. O., 2019, Effect of binder type, binder concentration and compacting pressure on some physical properties of carbonized corncob briquette, *Energy Reports*, Vol. 5, p. 909-918.
- Araújo, S., Boas, M. A. V., Neiva, D. M., De Cassia Carneiro, A., Vital, B., Breguez, M., Pereira, H., 2016, Effect of a mild torrefaction for production of eucalypt wood briquettes under different compression pressures, *Biomass and Bioenergy*, Vol. 90, p. 181-186.
- Bello, R. S., and Onilude, M. A., 2021, Effects of critical extrusion factors on quality of high-density briquettes produced from sawdust admixture, *MaterialsToday: Proceedings*, Vol. 38, p. 949-957.
- Carvalho, D. J., Morreti, R. R., Colodette, J. L., Bizzo, W. A., 2020, Assesment of the self-sustained energy generation of an integrated first and second generation ethanol production from sugarcane through the characterization of the hydrolysis process residues, *Energy Conversion and Management*, Vol. 203.
- De Almeida Moreira, B. R. Cruz, V. H., Cunha, M. L. O., Lopes, N. P., Megalhães, A. C., Miasaki, C. T., Caraschi, J. C., Da Silva Viana, R., 2021, Valorization of semi-solid by-product from distillation of cellulosic ethanol into blends for heating and power, *Waste Disposal and Sustainable Energy*, Vol. 3, p. 49-61.
- De Almeida Lima, U., 2019. *Industrial Biotechnology - Vol.3: Fermented and enzymatic processes (in Portuguese)*. Editora Blucher, São Paulo.
- Furtado, T. S., Valin, M., Brand, M. A., Bellote, A. F. J., 2010, Briquetting process variables and quality of forest biomass briquettes (*in Portuguese*), *Pesquisa Florestal Brasileira*, Vol. 30, p. 101-101.
- Godoi, I., Felipe, M. D. G. D A., Silva, D. D. V., Leonel, L. V., Costa, M. S. S. D. M., Sene, L., 2020, Characterization of the solid residue generation in the detoxification step of sugarcane bagasse hemicellulosic hydrolysate and behavior in agricultural soils, *Bragantia*, Vol. 79,p. 107-119.
- Kaliyan, N. and Morey, R. V, 2009, Factors affecting strength and durability of densified biomass products, *Biomass and bioenergy*, Vol. 33, p. 337-359.
- Križan, P., Matús, M., Soos, L', Beniak, J., 2015. Behavior of beech sawdust during densification into a solid biofuel, *Energies*, Vol. 8, p. 6382-6398.
- Lubwama, M, and Yiga, V. A., 2018, Characterization of briquettes developed from rice and coffee husks for domestic cooking applications in Uganda, *Renewable Energy*, Vol. 118, p. 43-55.
- Manyuchi, M. M., Mbohwa, C., and Muzenda, E., 2018, Value addition of coal fines and sawdust to briquettes using molasses as a binder, *South African Journal of Chemical Engineering*, Vol. 26, p. 70-73.
- Missagia, B., Guerrero, C., Narra, S., Sun, Y., Ay, P., Krautz, H. J., 2011, Physicomechanical properties of rice husk pellets for energy generation, *Energy and Fuels*, Vol. 25, p. 5786-5790.
- Pacheco, T.F., 2011. "Ethanol production: first or second generation?" (*in Portuguese*). *Circular Técnica (CNPAE)*, p. 6.
- RFA, 2022. *Annual Ethanol Production: U.S and World Ethanol Production*, Renewable Fuels Association RFA, <https://ethanolrfa.org/markets-and-statistics/annual-ethanol-production>. Accessed 01 June 2023.
- Sandes, L. V. O., Vieira, W. T., Albuquerque, A. A., Bezerra, P. X. O., Ribeiro, L. M.O., Carvalho, S. H. V., Solleti., J. I., Bispo, M. D., 2021, Pyrolysis of lignocellulosic waste from second-generation ethanol industry, *Sugar tech*, Vol. 23, p. 615-626.
- Sette Jr, C. R., Hansted, A. L. S., Novaes, E., Lima, P. A. F., Rodrigues, A. C., De Souza Santos, D. R., Yamaji, F. M., 2018a, Energy enhancement of the eucalyptus bark by briquette production. *Industrial Crops and Products*, Vol. 122, p. 209-213.

- Sette Jr, C. R., de Moraes, M. D. A., Coneglian, A., Ribeiro, R. M., Hansted, A. L. S., Yamaji, F. M., 2020b, Forest harvest byproducts: use of was as energy, *Waste Management*, Vol. 114, p. 196-201.
- Silva, D. A., Da Róz, A. L., Pires, A. A. F., Carvalho, A. M., Nakashima, G. T., Pádua, F. A., Yamaji, F. M., 2017, The influence of humidity on the mechanical properties of briquettes produced with wood residues (*Eucalyptus* sp. and *Pinus* sp.) (*in Portuguese*), *Revista Virtual de Química*, Vol. 9.
- Tumuluru, J. S., Wright, C. T., Hess, J. R., Kenney, K. L., 2011, A review of biomass densification systems to develop uniform feedstock commodities for bioenergy application, *Biofuels, Bioproducts and Biorefining*, Vol. 5, p. 683-707.
- Yank, A., Ngadi, M., and Kok, R., 2016, Physical properties of rice husk and bran briquettes under low pressure.

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