Ciência Florestal

ISSN 1980-5098
OPEN ACCESS

Ci. Fl., Santa Maria, v. 34, n. 4, e88531, p. 1-15, Oct./Dec. 2024 • https://doi.org/10.5902/1980509888531
Submitted: 7th/08/2024 • Approved: 10th/10/2024 • Published: 27th/12/2024

Articles

Residues generated by the productive chain of porongo (*Lagenaria siceraria* (Molina) Standl.) as an alternative source of bioenergy

Resíduos gerados pela cadeia produtiva do porongo (*Lagenaria siceraria* (Molina) Standl.) como fonte alternativa de recurso bioenergético

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ABSTRACT

The bottle gourd (*Lagenaria siceraria* (Molina) Standl.) is a fruit widely cultivated in southern Brazil for its use in the production of gourds, generating a large amount of waste obtained from the processing of the shell. In this context, the use of waste generated by the production chain of bottle gourds was evaluated as an alternative source of bioenergy through the production of briquettes. The chemical characterization of the residue was performed based on the contents of total extractives, lignin, carbohydrates and immediate chemistry (ash, volatile materials, and fixed carbon). Briquettes were produced through three different granulometric treatments for the processing of the material: *in natura* (Treatment 1), 10/20 mesh fraction (Treatment 2), and 20/40 mesh fraction (Treatment 3). The basic density and calorific value of the residue and the apparent, bulk, and energetic densities of the briquettes were also evaluated. The mechanical strength was determined based on the compression analysis of the briquettes. For the analyses of total extractives, lignin, carbohydrates, ash, fixed carbon, and volatile materials, values of 1.67%, 30.70%, 58.07%, 1.84%, 14.49%, and 83.67% were found, respectively. The basic density of the gourd shell was 0.24 g/cm³ and the calorific value was 3902.9 Kcal kg-1. The apparent densities were 1.03 g/cm³(1), 1.04 g/cm³(2), and 1.28 g/cm³(3) in bulk of 0.16 g/cm³ for the three treatments, and the energetic values were 4.07Mcal/m³(1), 4.09Mcal/m³(2) and 5.04Mcal/m³(3). For compressive strength, the briquettes resulted in values of 57.49MPa(1), 59.45MPa(2), and 74.36MPa(3). Through the treatments studied, the residue transformed into briquettes proved to be an alternative source of energy generation, with emphasis on Treatment 3. Based on the analyses performed, it was possible to conclude that residue from gourd shells presents desirable physical and chemical characteristics to be used as biomass for energy purposes.

Keywords: Bioenergy; Gourd; Processing; Agroindustrial waste; Sustainable energy

RESUMO

O porongo (*Lagenaria siceraria* (Molina) Standl.) é um fruto muito cultivado no Sul do Brasil pela sua utilização na confecção de cuias, gerando grande quantidade de resíduos obtidos do processamento da casca. Nesse contexto, avaliou-se o uso dos resíduos gerados pela cadeia produtiva da confecção de cuias de porongo como fonte alternativa de recurso bioenergético através da produção de briquetes. A caracterização química do resíduo foi realizada a partir dos teores de extrativos totais, lignina, carboidratos e química imediata (cinzas, materiais voláteis e carbono fixo). Foram produzidos briquetes com 3 diferentes tratamentos granulométricos obtidos do processamento do material: *in natura* (tratamento 1), fração 10/20 mesh (tratamento 2) e fração 20/40 mesh (tratamento 3). A densidade básica e o poder calorífico do resíduo e densidades aparente, a granel e energética dos briquetes também foram avaliadas. Foi determinada a resistência mecânica a partir da análise de compressão dos briquetes. Para as análises de extrativos totais, lignina, carboidratos, cinzas, carbono fixo e materiais voláteis, foram encontrados valores de 1,67%, 30,70%, 58,07%, 1,84%, 14,49% e 83,67% respectivamente. A densidade básica da casca do porongo foi de 0,24g/cm³ e o poder calorífico de 3.902,9Kcal kg-1. Para densidades aparente de 1,03g/cm³(1), 1,04g/cm³(2) e 1,28g/cm³(3), a granel de 0,16g/cm³ para os três tratamentos e energética de 4,07Mcal/m³(1), 4,09Mcal/m³(2) e 5,04Mcal/m³(3). Para a resistência à compressão os briquetes resultaram em valores de 57,49MPa(1), 59,45MPa(2) e 74,36MPa(3). Nos tratamentos estudados, o resíduo na forma de briquetes se mostrou uma alternativa para geração de energia, com destaque para o tratamento (3). A partir das análises realizadas, foi possível concluir que o resíduo da casca do porongo apresenta características físico-químicas desejáveis para ser utilizado como biomassa para fins energéticos.

Palavras-chave: Bioenergia; Cuia; Processamento; Resíduo agroindustrial; Energia sustentável

1 INTRODUCTION

The increase in renewable energy sources has become necessary in recent years due to population growth and development. The demand for technologies, the interest in reducing pollution, and consequently, climate change, make the development of sustainable energy a goal to be achieved and should guide the search for advances in technological research and its applications (Silva *et al*., 2022). According to Brás (2024), improperly discarded waste increases the potential for pollution; however, the valorization of waste reuse is an important tool for reducing this liability and provides more appropriate destinations for such waste.

Brazil stands out for its energy production from plant biomass, which are important energy sources in view of the country's geographical location and favorable climate (Ferreira *et al*., 2023). In agroindustrial systems, large amounts of waste are generated during the transformation processes of raw materials into products, and part of such waste is improperly discarded, causing environmental contamination. Many such wastes come from plant-based raw materials and can be used as bioenergy, meaning a clean, sustainable, and renewable energy source through the classification and transformation of such material into briquettes or pellets (Almeida *et al*., 2023).

The bottle gourd (*Lagenaria siceraria* (Molina) Standl.) is a fruit of the Cucurbitaceae family. Its use is common in southern Brazil and in countries such as Argentina and Uruguay, where it is widely used in the production of gourds for *chimarrão*, an important part of the daily culture in these regions. It is also used in the production of handicrafts or as containers for food and beverages (Paust & Lourenço, 2017). According to the same authors, only the upper part of the bottle gourd is used for the production of gourds, while the lower part is discarded, generating significant amounts of waste. According to Nejeliski (2022), during the processing of gourds, about 80% of the initial volume of the fruit is turned into waste and subsequently discarded.

As an alternative for the use of agro-industrial wastes such as bottle gourd, the densification of the material for the production of briquettes and pellets can be a way to utilize and add value. Briquetting is the process of compacting a material through controlled temperature and pressure, proving to be efficient in concentrating biomass (Souza *et al*., 2022). Briquettes can be used both industrially and domestically as an alternative source to firewood and charcoal, facilitating storage, transportation, and handling (Nunes *et al*., 2022).

In this context, the present study aimed to evaluate the use of waste generated by the production chain of bottle gourd gourds in the production of briquettes, with the goal of presenting alternatives for renewable energy generation and the proper disposal of this waste.

2 MATERIALS AND METHODS

This study was conducted at the Wood Chemistry Laboratory (LAQUIM) of the Federal University of Santa Maria (UFSM/Brazil) using the shell residues of *Lagenaria siceraria* (Molina) Standl. collected in the district of Arroio do Só, in the locality of Rincão Nossa Senhora Aparecida, in the city of Santa Maria, state of Rio Grande do Sul, Brazil. In this location, an average of 10,000 bottle gourds are produced per hectare, generating a residual volume of 2,700 m³ across 300 hectares of planted area.

2.1 Analyses of biomass

The collected material was air-dried until it reached an equilibrium moisture content (EMC) of approximately 12%. Part of the residue was processed in a hammer mill and later turned into sawdust using a Willey mill. The sawdust was classified using sieves attached to an electromagnetic shaker, with the 40/60-mesh fraction being used for chemical analyses. The remaining residues were classified using 10/20-mesh and 20/40-mesh sieves.

For the chemical and energetic characterization of the material, the moisture content (TAPPI T210 cm-93), total extractives (TAPPI T204 cm-97), insoluble lignin (TAPPI T222 om-02), soluble lignin (TAPPI UM 250), and average carbohydrate content, according to the Abaide standard (2021), were determined. Immediate chemical analysis was performed following the technical standard NBR 8112 (ABNT, 1983), determining the contents of volatile material, ash, and fixed carbon.

The determination of the higher calorific value (HCV), in kcal kg-1, was carried out at the Laboratory of Bromatology and Ruminant Nutrition (LABRUMEN) at the Federal University of Santa Maria, using a bomb calorimeter, following NBR 8633 (ABNT, 1984). The lower calorific value (LCV) was calculated using Equation (1), developed by Doat (1977) and cited by Silva *et al*. (2019). The useful calorific value (UCV) was calculated according to Equation (2), as outlined by Souza (2010).

$$PCI = PCS - 600 * ((9 * 6) / 100) \quad (1)$$

where: PCI = Lower Heating Value; PCS = Higher Heating Value.

$$PCU = ((PCI - 6 * U) / (100 + U)) * 100 \quad (2)$$

where: PCI = Lower Heating Value; PCU = Useful Heating Value; U = Dry Basis Moisture Content.

The basic density of the residue was determined using the hydrostatic balance method (Vital, 1984). The apparent density of the briquettes was determined by the stereometric method; i.e., by the mass/volume ratio at a given moisture content. Since they are cylindrical, the diameters of the briquettes were measured at three points (base, middle, and top) using a digital caliper with a precision of 10^{-3} mm. The mass of the briquette was determined using an analytical balance with a precision of 10^{-2} g. The bulk density of the residues was determined using a 50 mL beaker. The mass of the sample was measured, and the bulk density was then calculated.

The energetic density of the briquettes was calculated using the product of the useful calorific value (UCV) and the apparent density (AD), according to Equation (3):

$$DE = \frac{PCU \cdot DA}{1000} \quad (3)$$

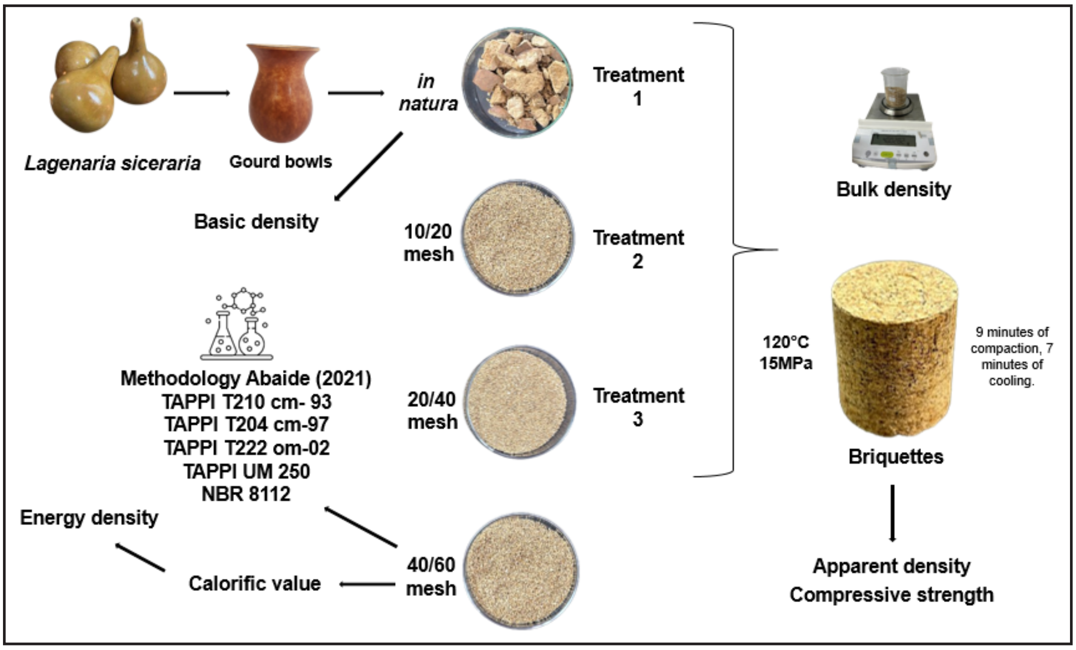
where: DE = Energy Density (Mcal/m³); PCU = Useful Heating Value (kcal/g); DA = Apparent Density (g/cm³).

2.2 Production of briquettes

For the production of the briquettes, three treatments of bottle gourd shell residues were used: *in natura* fraction (Treatment 1), 10/20-mesh fraction (Treatment

2), and 20/40-mesh fraction (Treatment 3), with five repetitions for each treatment. The original fraction was also used for determining basic, apparent, and bulk densities. Figure 1 illustrates the transformation of the bottle gourd into a gourd, the generated residues, the preparation of these residues for physical-chemical analyses, and the production of the briquettes.

Figure 1 – Graphical representation of the preparation of *Lagenaria siceraria* (Molina) Standl. residue for chemical-physical and energetic characterization and briquette production



Source: Authors (2024)

2.3 Evaluation of briquetes

Five briquettes were produced per treatment (totaling 15 briquettes) according to the TAPPI T 264 om-88 standard, using a Lippel LB-32 briquette press, with a pressure of 15MPa, a temperature of 120 °C, and compaction and cooling times of 9 and 7 minutes, respectively.

The mechanical compression strength test was performed on a universal testing machine model EMIC, in which the briquettes, after acclimatization in a climate chamber (20°C and 65% humidity), were compressed perpendicularly to their height at a rate of 0.3mm/min until the point of rupture, following a methodology adapted from the NBR ISO 11093-9 standard.

The data from the mechanical resistance analysis were subjected to statistical analysis using Dunnett's test for mean comparison with an alpha value of 0.05, employing the OriginLab software.

3 RESULTS AND DISCUSSIONS

As shown in Table 1, the values found for the chemical composition of the bottle gourd shell residues were: 1.67% total extractives, 0.8% soluble lignin, 29.89% insoluble lignin (30.70% total lignin), and 58.07% carbohydrates (cellulose + hemicellulose). To determine the quality of biomass for use as fuel, it is essential to analyze and understand its chemical composition (Brand, 2010).

Table 1 – Results of the chemical analyses of the porongo peel residue]

Chemical analyses	Porongo peel residue (%)
Total Extractives	1.67
Total lignin (soluble + insoluble)	30.70
Carbohydrates (cellulose + hemicellulose)	58.07
Ash	1.84
Volatile matter	83.67
Fixed carbon	14.49

Source: Authors (2024)

When compared to other plant biomasses traditionally used for energy, such as sugarcane bagasse, the bottle gourd shell residue exhibited low levels of extractives and carbohydrates but high lignin content. According to Triana *et al*. (1990), sugarcane bagasse presented 2.5% extractives, 20.7% lignin, and 71.80% carbohydrates.

Thus, considering that lignin is the main chemical constituent responsible for increasing the calorific value of plant biomass, as it contains between 60% to 64%

elemental carbon in its composition. Moreover, lignin is highly resistant to thermal degradation due to its complex reticulated structure, which is related to the carbon-carbon (C_3-C_6) bonds formed during the lignification process (Carvalho, 2022). The bottle gourd shell residue yielded favorable chemical composition values for use as fuel; for instance, in furnaces, stoves, and boilers.

In Table 1, the results of the analyses of ash, volatile materials, and fixed carbon show that the bottle gourd shell residue yielded values close to those found in the literature for the immediate chemical composition of forest or agro-industrial residues, such as eucalyptus, which has a volatile material index ranging from 75% to 85% and a fixed carbon index between 15% and 25% (Brand, 2010), and corn cob, which is composed of 1.60% ash, 83.11% volatile materials, and 15.27% fixed carbon (Silva *et al*., 2019).

According to Brand (2010), the volatile content indicates how easily a material can be burned, being inversely proportional to the fixed carbon content. Therefore, fuels with high fixed carbon indices (low volatile indices) will burn more slowly. Furthermore, the higher the fixed carbon content, the more energetic the biomass will be, although volatile materials also generate energy during combustion processes. The bottle gourd shell residue resulted in a low ash content, which is favorable because the inorganic material is associated with a significant amount of silica (SiO_2), reducing the calorific value of the biomass (Butler *et al*., 2011).

The moisture content of the bottle gourd shell residue obtained in this study was 8.38%, in accordance with the recommended range in the literature (between 8% and 15%) for plant biomass used in briquette production (Paula, 2010; Brand *et al*., 2014). According to Brand *et al*. (2014), the net calorific value of a material is closely related to its moisture content; the higher the moisture content, the lower the calorific value.

Basic density is one of the most important physical properties for the technological characterization of a material (Schulz *et al*., 2020). The bottle gourd can be considered a lightweight material, with a basic density of 0.24g/cm³, compared to bamboo (0.80g/cm³) and cork (0.30g/cm³) (Ashby; Johnson, 2011).

In the present study, the bottle gourd shell residue yielded a higher calorific value (HCV) of 4,632.2kcal kg-1, a lower calorific value (LCV) of 4,308.5kcal kg-1, and a useful calorific value (UCV) of 3,902.9kcal kg-1 when compared to other agro-industrial residues such as rice husk and sugarcane bagasse. Silva *et al*. (2022), studying the culms of Dendrocalamus giganteus for energy purposes, obtained calorific values close to those found for the bottle gourd, at 4,495.2kcal kg-1 (HCV) and 4,171.0kcal kg-1 (LCV), but higher than the HCV values found for rice husk residue (3,850.0kcal kg-1) and sugarcane bagasse (4,100.0kcal kg-1) (Brand, 2010).

The calorific value is directly related to the viability of using biomass as an energy resource, expressing the energetic potential of the material. Together with density, these properties dictate the performance of biomass as a fuel (Souza; Vale, 2016).

As previously mentioned, chemical composition influences the calorific value of biomass. Thus, the low ash content and high lignin content of the bottle gourd (Table 1) favored the high energy output generated by this fuel. Ashes have an inverse relationship with calorific value and are accounted for in the mass of the fuel subjected to the combustion process (Chaves *et al*., 2013). Conversely, the content of volatile materials and fixed carbon has a direct relationship with calorific value during the combustion process, prolonging the burning of biomass (Silva *et al*., 2022).

Table 2 presents the values of bulk, apparent, and energetic densities of the briquettes produced with the three treatments of the residues.

Table 2 – Averages of bulk, apparent, and energy densities of briquettes obtained from the treatments of porongo peel residue

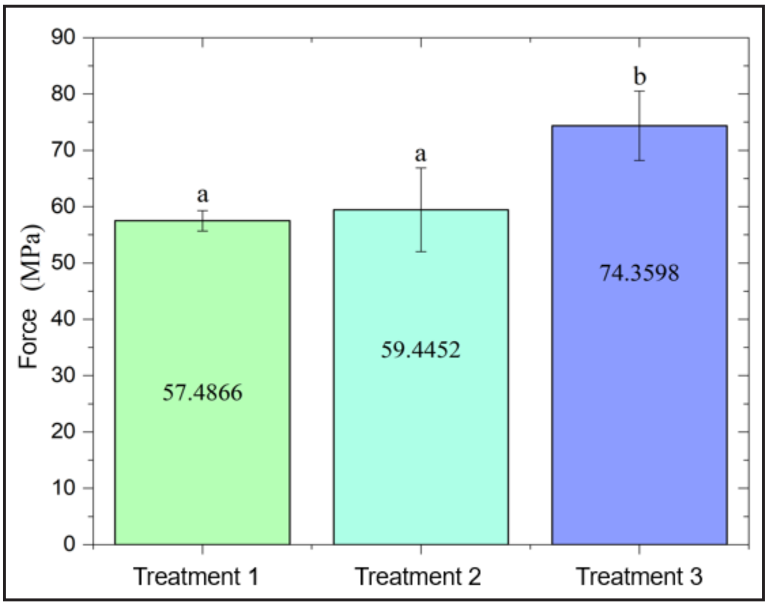
Treatments	Bulk Density (g/cm³)	Apparent Density (g/cm³)	Energy Density (Mcal/m³)
1	0.16	1.03	4.07
2	0.16	1.04	4.09
3	0.16	1.28	5.04

Source: authors (2024)

In where: Treatment 1 = *in natura*; Treatment 2 = fraction 10/20 mesh; Treatment 3 = fraction 20/40 mesh.

According to Table 2, the bulk density of the briquettes from the bottle gourd residue treatments was similar to that found in a study conducted by Fernandez *et al*. (2017) for briquettes produced with Pinus spp. wood (0.17g/cm³) and sugarcane bagasse (0.16g/cm³). According to Saccol *et al*. (2020), bulk density is a critical parameter in the use of biomass for energy. The authors state that the higher this property, the better, as the goal is to develop less voluminous products, meaning more compact and dense ones. The densest briquettes with the highest energetic density were obtained with treatment (3), possibly due to better compaction promoted by the smaller particle size of the residue (20/40-mesh fraction), which resulted in a reduction in the volume of the briquette for the same weight of material. According to Brand (2010), apparent density, in addition to being influenced by moisture content, is directly proportional to particle size when its determination is made by the bulk method. Figure 2 presents the average compression resistance values of the briquettes produced in the three treatments.

Figure 2 – Compression resistance of briquettes produced with different treatments of porongo peel residues



Source: Authors (2024)

In where: The bars represent the mean ± standard deviation at 0.05% significance.

The briquettes produced from the different treatments of bottle gourd residues resulted in average values of 57.49MPa (1), 59.45MPa (2), and 74.36MPa (3). Treatment 3 resulted in briquettes with the highest compressive strength (74.33MPa), which can be explained by its greater apparent density (Table 2). Compressive strength is important as it is directly related to the handling, transport, and storage of the briquettes (Ferreira *et al*., 2023). According to Souza *et al*. (2022), particle size is directly related to the physical-mechanical resistance of the briquettes; that is, the smaller the particle size, the greater the resistance and the adjustment of the particles, as it increases the apparent density of the residues through the mass/volume ratio, which was corroborated in this study.

3 CONCLUSIONS

The residues from the bottle gourd shell (*Lagenaria siceraria* (Molina) Standl.) exhibit favorable chemical properties for use as an energy resource, showing low ash content and high lignin content.

The densest briquettes with the highest energetic density were obtained from Treatment 3, as well as presenting the highest compressive strength. New studies are suggested for briquette production under different temperatures and pressures.

The bottle gourd shell residue is a biomass with excellent physical-chemical characteristics for energy purposes, allowing for the transformation of this waste into briquettes, adding value to the residue and diversifying energy sources. This presents an alternative for the large amounts of waste generated in gourd production in southern Brazil.

ACKNOWLEDGMENTS

The authors would like to thank the Technical Assistance and Rural Extension Company (EMATER) of the state of Rio Grande do Sul for their collaboration and support in providing the research material used in this study.

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How to quote this article

WACHT, W. L.; FARIAS, D. T.; COLDEBELLA, R.; SILVA, G. T.; LOUREIRO FILHO, M. F.; FARIAS, J. A.; PEDRAZZI, C. Residues generated by the productive chain of porongo (*Lagenaria siceraria* (Molina) Standl.) as an alternative source of bioenergy. **Ciência Florestal**, Santa Maria, v. 34, n. 4, e88531, p. 1-15, 2024. DOI 10.5902/1980509888531. Available from: https://doi.org/10.5902/1980509888531. Accessed in: day month abbr. year.