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ARTÍCULO

Physical, mechanical, and energetic performance of briquettes from MDF and wood residues

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Abstract:
In the forest production process, large quantities of lignocellulosic residues are generated, requiring strategies for their valorization and reuse. This study evaluated the physical, mechanical, and energetic performance of briquettes produced from *Pinus* sp. sawdust and from mixtures of MDF industry residues with *Pinus* sp. and *Eucalyptus* spp. sawdust. The briquettes were characterized in terms of apparent density, friability, and energetic properties, including proximate analysis and higher, lower, and net heating values. The results show that raw material composition has a direct influence on briquette performance. Briquettes produced from *Pinus* residues exhibited superior energetic properties, whereas those containing *Eucalyptus* presented higher apparent density and lower fines generation, indicating greater physical stability. The incorporation of MDF industry residues in combination with sawmill materials represents a viable alternative for producing briquettes with more balanced physical and energetic properties, contributing to the utilization and energy recovery of lignocellulosic residues.

Keywords: Biomass briquettes, biomass densification, bioenergy, density, heating values, MDF residues, wood residues.

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Introduction

The generation of lignocellulosic residues in the forest and wood-processing industries represents both an environmental challenge and an opportunity for energy recovery. Large volumes of residues are produced due to inefficiencies in harvesting and processing operations, including wood chips, sawdust, and panel residues. Although often underutilized or disposed of as waste, these residues have gained attention as alternative feedstocks for bioenergy production, contributing to waste reduction and the development of renewable energy systems. Among the available technologies, briquetting has been adopted as an efficient densification process that converts low-density biomass into a compact, high-energy-density fuel. This process improves handling, storage, and transportation characteristics, while also enhancing the energy potential of lignocellulosic materials. As a result, briquettes have been produced from a variety of raw materials.

The physical, mechanical, and energetic properties of briquettes are influenced by the type, composition, and characteristics of the raw materials. Factors such as particle size, moisture content, and material homogeneity play an important role in determining density, durability, and energy performance. Previous studies have investigated the briquetting of wood residues, agricultural by-products, and different lignocellulosic materials, highlighting how raw material characteristics can affect briquette quality and energy performance (Protásio *et al*., 2011; Niño *et al*., 2020; Souza *et al*., 2022; Roman and Grzegorzewska, 2024; Kamdem *et al*., 2025; Souza *et al*., 2024). However, most studies have focused on single raw materials or more homogeneous biomass sources, while fewer studies have evaluated mixtures of heterogeneous industrial residues.

In the wood panel industry, significant amounts of residual materials are generated, including MDF waste, which differs from conventional wood due to its composition, particle structure, and the presence of additives. When combined with sawmill-derived materials, these residues may exhibit distinct behavior during densification, affecting briquette performance.

Comparative experimental studies evaluating the performance of briquettes produced from mixed residues, particularly the combination of MDF and sawmill residues, remain limited, especially in comparison with commercial briquettes. This limitation hinders the assessment of the technical feasibility of these materials as alternative biofuels.

The objective of this study was to comparatively evaluate the physical, mechanical, and energetic properties of briquettes produced from a mixture of MDF (medium-density fibreboard) and *Pinus* sp. sawmill residues, in comparison with briquettes produced solely from sawmill residues and with commercial briquettes made from *Eucalyptus* spp.

Materials and methods

The briquettes used in this experiment were categorized into three batches. Batch 1 was produced by the same company and consisted of MDF panels and residues generated during the sawing of *Pinus* sp. logs. Batch 2 consisted of sawmill residues of *Pinus* sp. Batch 3 was obtained through purchase, and according to the manufacturer's description, it consisted of compacted sawdust from *Eucalyptus* spp. A total of 10 kg of briquettes from batches 1 and 2, and 13 kg from batch 3, were employed. The latter was used as a control since it is an established product and serves as a reference in the market.

The company responsible for producing batches 1 and 2 possesses two Biomax briquette machines, model B 95/210, with a capacity of 1550 $kg \cdot h^{-1}$ and a 55.95 kW motor. The moisture content, on a dry basis, of the wood residues used was 16 % (Table 1).

Table 1: Characteristics of the briquettes used in the experiment.

Batch	Origin / Manufacturer	Composition	Quantity Used (kg)	Purpose / Notes	Production Equipment	Raw Material Moisture (% dry basis)
1	Company A	MDF panels + sawing residues of *Pinus* sp.	10	Experimental batch	Biomax B 95/210, 1550 kg/h, 55950 W	16
2	Company A	Sawmill residues of *Pinus* sp.	10	Experimental batch	Biomax B 95/210, 1550 kg/h, 55950 W	16
3	Purchased (Manufacturer B)	Compacted sawdust of *Eucalyptus* spp.	13	Control batch / market reference	Not specified	Not specified

Physical properties

The apparent density of the briquettes was determined in accordance with the ABNT NBR7190-3 (2022) standard, utilizing four measurements of diameters and lengths to calculate the volume.

Moisture contents, both on a dry basis (TU_{BS}) and a wet basis (TU_{BU}), were determined following the guidelines of ABNT NBR 14929 (2017).

Immediate chemical analysis

The volatile, ash and fixed carbon contents were determined following the ASTM D1102-84 (2021) standard.

Heating values

The higher heating value (HHV) of the briquettes was determined according to the ISO 18125:2017 (2017), using an adiabatic bomb calorimeter. Additionally, the lower heating value (LHV) and the net heating value (NHV) were determined.

Friability

The friability test was conducted using a Fribilometer, specifically the MA791 model from the Marconi Company. The Fribilometer operated at a rotation speed of 25 ± 2 revolutions per minute (RPM) for a duration of 6 minutes. Subsequently, the resulting material from the impact and abrasion resistance test was sieved using a 4 mesh (4.76 mm) sieve. The material passing through the sieve was considered fines. This procedure was an adaptation of the ABNT NBR8740 (1985) standard.

The remaining material, along with the fines, was weighed to determine the friability of the material.

Statistical analysis

Comparative analyses were conducted using the statistical program Assistat version 7.7 beta (Silva and Azevedo 2016). Analysis of variance (ANOVA) was performed, employing completely randomized experiments, which yielded means and Tukey's test at a 5 % probability level. For the density analysis, five repetitions were carried out, while the determination of moisture content had four repetitions. Three repetitions were conducted for immediate chemical analysis, five for the friability test, and four for the determination of the higher heating value.

Results and discussion

The lowest dry basis moisture content (TU_{BS}) was observed in batch 1 (7.83%), whereas batch 2 exhibited the highest value (11.21%). This difference is likely associated with the lower moisture content of MDF panels compared to the residues used in batch 2, reflecting the distinct characteristics of the raw materials and the production process (Figure 1).

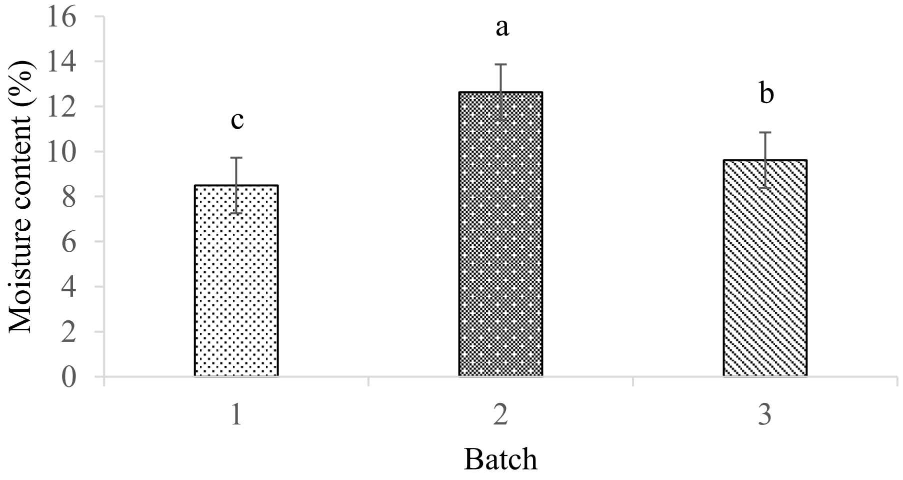

Figure 1: Dry basis moisture content (%) of the briquettes produced from the mixture of residues from *Pinus* sp. cutting and MDF panels (batch 1), briquettes produced from *Pinus* sp. cutting residues (batch 2), and from *Eucalyptus* spp. cutting residues (batch 3).

Moisture content is a relevant parameter in the briquetting process, influencing densification and mechanical performance. According to Silva *et al*. (2015), values around 12% favor compaction, although the optimal range may vary depending on the raw material (Dias *et al*., 2012). In this context, the moisture content of batch 2 (11.21%) is closer to the values commonly reported in the literature, whereas batch 1 (7.83%) is near the lower limit.

Moisture contributes to the plasticization of lignocellulosic components, particularly lignin, increasing molecular mobility during pressing and promoting material cohesion and mechanical strength. On the other hand, higher moisture levels may lead to vapor formation during compaction, resulting in structural defects in the briquettes. Thus, differences in moisture content between batches may influence compaction behavior and the integrity of the produced briquettes.

In addition to its effects on densification, moisture content also influences the energetic performance of briquettes. Lower moisture levels tend to increase combustion efficiency, as a greater fraction of the mass consists of combustible material. Roman and Grzegorzewska (2024) reported that moisture levels around 15% favor energy generation, while Furtado *et al*. (2012) observed a significant negative correlation between moisture content and net heating value. In this sense, the lower moisture content observed in batch 1 may represent an advantage from an energy standpoint.

The apparent density of batch 3 (1210 kg·m^{-3}) was higher than that of batch 1 (865 kg·m^{-3}) and batch 2 (937 kg·m^{-3}) (Figure 2). This difference is likely associated with the finer granulometry and greater uniformity of the material used in batch 3, whereas batches 1 and 2 were produced from heterogeneous residues, including wood chips, sawdust, and MDF, without particle size classification. In addition, the greater variability observed in batches 1 and 2 may be related to less controlled moisture content prior to briquetting.

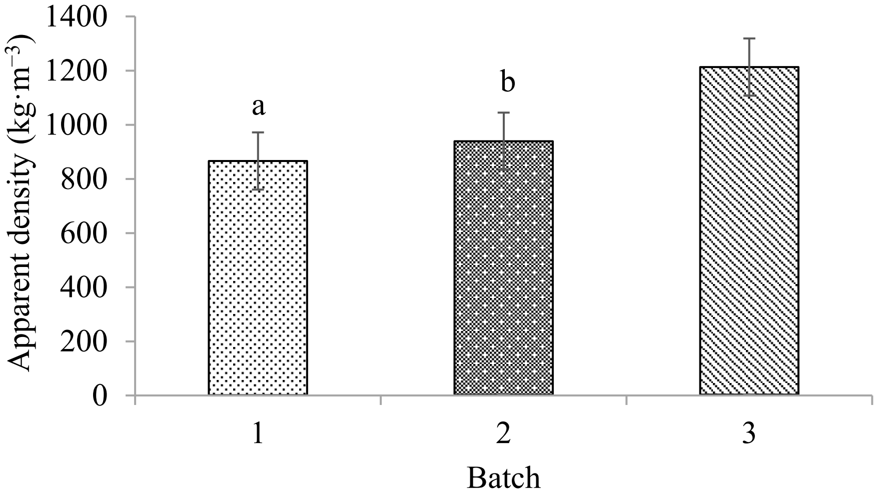

Figure 2: Apparent density (kg·m^{-3}) of the briquettes produced from the mixture of residues from *Pinus* sp. cutting and MDF panels (batch 1), briquettes produced from *Pinus* sp. cutting residues (batch 2), and from *Eucalyptus* spp. cutting residues (batch 3).

The density values obtained for batches 1 and 2 were lower than those reported by Amorim *et al.* (2015), who observed approximately 1230 kg·m^{-3} for briquettes produced from *Pinus* sp. sawdust. This difference is likely related to the higher material homogeneity and smaller particle size reported by those authors, which favor densification during briquetting. In contrast, the use of heterogeneous lignocellulosic residues in the present study may have limited particle compaction and interparticle bonding, resulting in lower apparent density.

The density values obtained in this study fall within the range reported in the literature for briquettes produced from lignocellulosic residues, typically between 700 and 1200 kg·m^{-3}, depending on raw material characteristics and particle heterogeneity (Dias *et al.*, 2012), indicating intermediate densification performance associated with mixed and heterogeneous biomass sources.

Density differences are also reflected in the friability results (Figure 3). Batch 1, which exhibited the lowest density, also showed the highest friability, indicating reduced mechanical integrity and weaker interparticle cohesion. In contrast, batches 2 and 3 presented lower friability values (below 1%), suggesting greater structural stability and improved resistance to mechanical disintegration, despite differences in raw material composition.

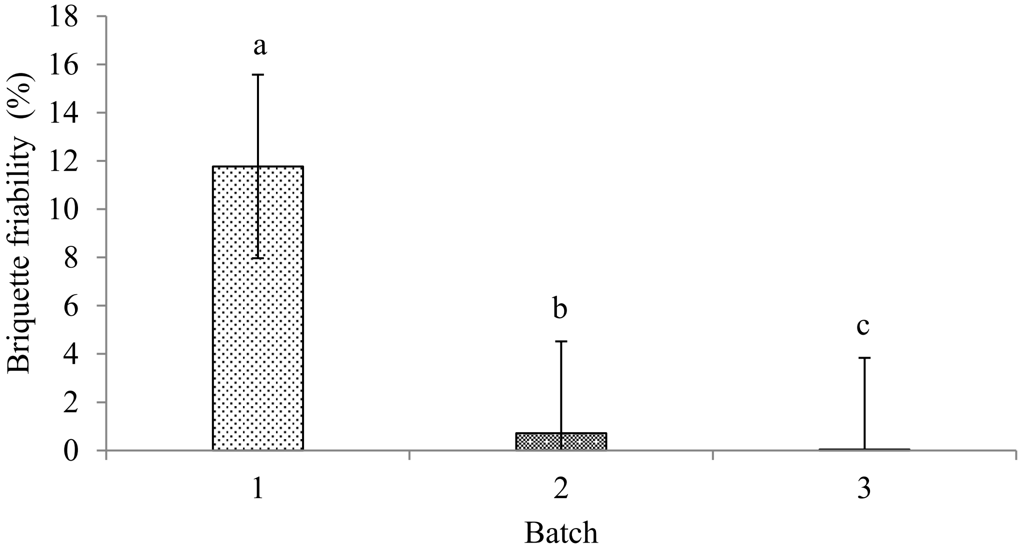

Figure 3. Briquette friability (%) of briquettes produced from mixtures of *Pinus* sp. residues and MDF panels (batch 1), *Pinus* sp. cutting residues (batch 2), and *Eucalyptus* spp. cutting residues (batch 3).

In addition to the constituent material, several factors may influence friability test results, including test duration, drop height, and the number of samples tested simultaneously. These variables can increase mechanical stress during testing and, consequently, affect the amount of fines generated (Gilvari *et al.*, 2019). Therefore, friability is an important indicator for evaluating handling behavior, storage stability, and logistical performance of briquettes.

Briquettes that generate lower amounts of fines during the friability test are considered more resistant to mechanical degradation. This test, together with the diametral compression strength test, is commonly used to evaluate the mechanical performance of densified biomass products (Silva *et al.*, 2015).

Batch 3 exhibited the highest average apparent density and the lowest fines generation during testing (Figure 4).

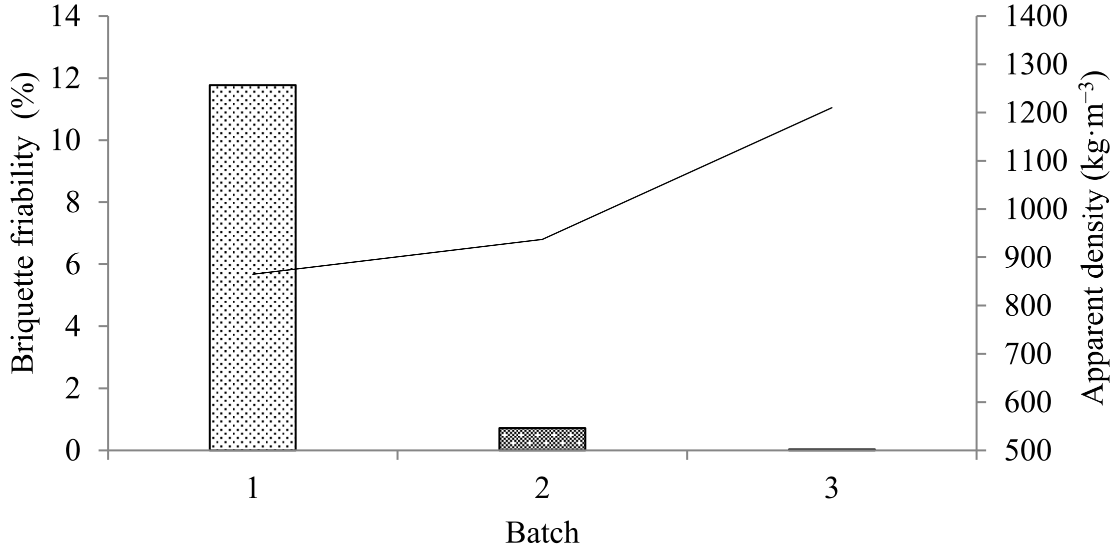

Figure 4: Briquette friability (%) and apparent density (kg·m^{-3}) of briquettes produced from mixtures of *Pinus* sp. residues and MDF panels (batch 1), *Pinus* sp. cutting residues (batch 2), and *Eucalyptus* spp. cutting residues (batch 3). Bars represent friability values, while the line represents apparent density.

Particle size is relevant in briquette formation, since smaller particles contribute to more effective interactions under compression, improving densification and final strength (Silva *et al.*, 2015). However, although finer particles generally favor the production of denser briquettes, higher pressure and temperature are required to ensure adequate consolidation without the use of additional binders (Dias *et al.*, 2012; Wu *et al.*, 2025). In this context, increased temperature promotes lignin softening, which enhances interparticle cohesion and contributes to greater resistance to moisture variations (Furtado *et al.*, 2010).

In general, raw materials with smaller particle size tend to improve compaction and mechanical resistance of briquettes. However, Silva *et al.* (2015) reported that, although briquettes produced from *Pinus* sp. sawdust exhibited higher density than those produced from *Eucalyptus* sp., the latter showed higher mechanical strength. The authors also classified *Pinus* briquettes as having medium friability, while *Eucalyptus* briquettes were classified as low friability.

The highest ash content was observed in briquettes from batch 1 (1.49%) (Figure 5), which may be associated with differences in raw material composition, particularly the inclusion of sawmill residues and MDF panels. MDF residues may contribute to ash content due to inorganic compounds related to the adhesives used in panel manufacturing.

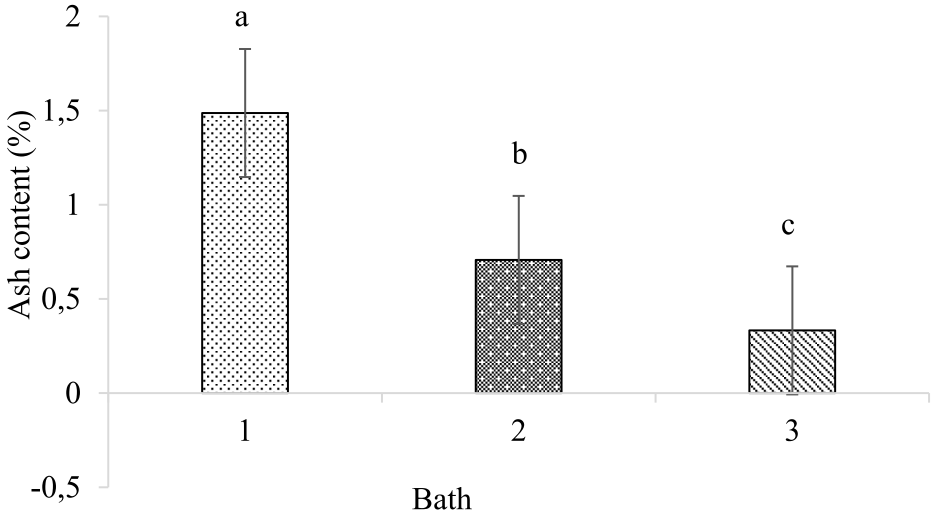

Figure 5: Ash content (%) of the briquettes produced from the mixture of residues from *Pinus* sp. cutting and MDF panels (batch 1), briquettes produced from *Pinus* sp. cutting residues (batch 2), and from *Eucalyptus* spp. cutting residues (batch 3).

Ash content in lignocellulosic briquettes can vary widely depending on biomass type and processing conditions, with values reported in the literature ranging from 0.40% to 27.93% (Marreiro *et al*., 2021). In the present study, ash contents remained at the lower end of this range, suggesting favorable characteristics for energy applications. Values around 4% are generally considered suitable for solid biofuels (Padilla *et al.,* 2016).

The lowest ash content was observed in briquettes from batch 3 (0.33%), indicating a reduced amount of inorganic residue after combustion. This may be advantageous for end-use applications such as fireplaces, barbecues, ovens, and boilers. Higher inorganic contents in lignocellulosic residues, particularly in bark and MDF, are generally associated with the intrinsic mineral composition of the raw materials and the concentration of inorganic elements in the dry fraction (Souza *et al*., 2024).

The volatile matter content did not show significant differences among the three briquette batches. Similar values have been reported in the literature for lignocellulosic materials and wood-based residues. Portilho (2021) observed volatile contents of 81.50% for raw MDF and 82.69% for coated MDF intended for briquette production. Likewise, Brand (2010) reported values of 82.54% for coniferous woods and 81.42% for hardwoods, while Paula *et al*. (2011) found a range between 78% and 84% for wood residues such as sawdust and shavings.

Higher volatile matter contents generally increase fuel reactivity during combustion, since a larger fraction of volatile compounds is released during thermal degradation, accelerating ignition and combustion processes.

Proper segregation of residues, including sawdust, shavings, panels, and sawn wood, is essential for their efficient utilization. In addition, operator training is important for improving storage, classification, quantification, reuse, and conversion of these materials into value-added products. Attention should be given to the composition of panel-derived products, such as briquettes produced from MDF, since they may release gases that can cause health risks such as irritation, allergies, and intoxication (Nunes and Serra, 2019; Moreno *et al*., 2016).

The fixed carbon content was similar among the three briquette batches, ranging from 16.21% to 18.21%, which is consistent with values reported by Paula (2010), who indicated that fixed carbon in wood residues typically ranges between 16% and 21%. Amorim *et al*. (2015) reported a fixed carbon content of 11.53% for briquettes produced from *Pinus* sp. sawdust, while Brand (2010) reported values of 17.7% for coniferous woods and 17.82% for hardwoods.

The higher heating value (HHV) of briquettes from batch 2 was similar to that of batches 1 and 3. However, significant differences were observed between batches 1 and 3 (Figure 6). These variations may be associated with differences in lignin structure, which influence thermal degradation resistance due to its high chemical stability and the greater energy required for decomposition (Ház *et al.*, 2019). According to Portilho (2021), a higher proportion of guaiacyl units, commonly found in coniferous woods, may increase thermal resistance due to the presence of carbon at position 5, which favors carbon–carbon bond formation and enhances polymerization during lignin biosynthesis.

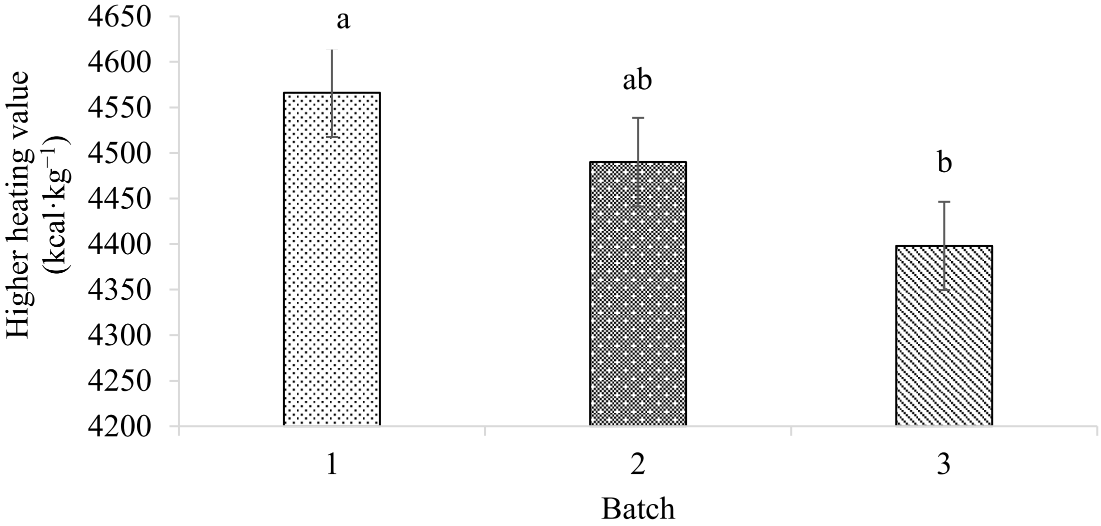

Figure 6: Higher heating value (kcal·kg^{-1}) of the briquettes produced from the mixture of residues from *Pinus* sp. cutting and MDF panels (batch 1), briquettes produced from *Pinus* sp. cutting residues (batch 2), and from *Eucalyptus* spp. cutting residues (batch 3).

The higher heating value (HHV) of the briquettes showed a similar trend to ash content. Briquettes produced from MDF panels and *Pinus* sp. residues exhibited higher HHV compared to those produced with *Eucalyptus* spp. sawdust. This behavior may be associated with the presence of adhesives such as urea-formaldehyde in the MDF panels used in batch 1, which can influence both energy content and ash formation. In addition, differences in the proportion of contaminants derived from *Pinus* sp. processing may have also contributed to this variation.

Farage *et al*. (2013) evaluated the energy potential of wood waste reuse, including MDF, plywood, particleboard, and solid wood residues generated at the Furniture Center of Ubá, MG, Brazil. The authors reported HHV values of 4632 kcal·kg^{-1} for a mixture of MDF, particleboard, plywood, and wood residues, 4730 kcal·kg^{-1} for solid wood residues, 4732 kcal·kg^{-1} for MDF residues and 4095 kcal·kg^{-1} for a mixture of MDF, particleboard, and plywood residues. Amorim et al. (2015) reported an HHV of 4408 kcal·kg^{-1} for briquettes produced from *Pinus* sp. Similarly, Cunha et al. (2018), evaluating MDF residues for pellet production, obtained an average HHV of 4427.8 kcal·kg^{-1}.

Günther *et al*. (2012) reported that variations in chemical composition and binder content in engineered wood products may alter their energy potential by up to 15% when considered individually.

The net heating value (NHV) of briquettes from batches 2 and 3 showed similar values, whereas batch 1 exhibited the highest NHV. Although no significant difference in HHV was observed between batches 1 and 2, the higher moisture content in batch 2 (Figure 7) reduced its NHV, resulting in lower available energy for combustion.

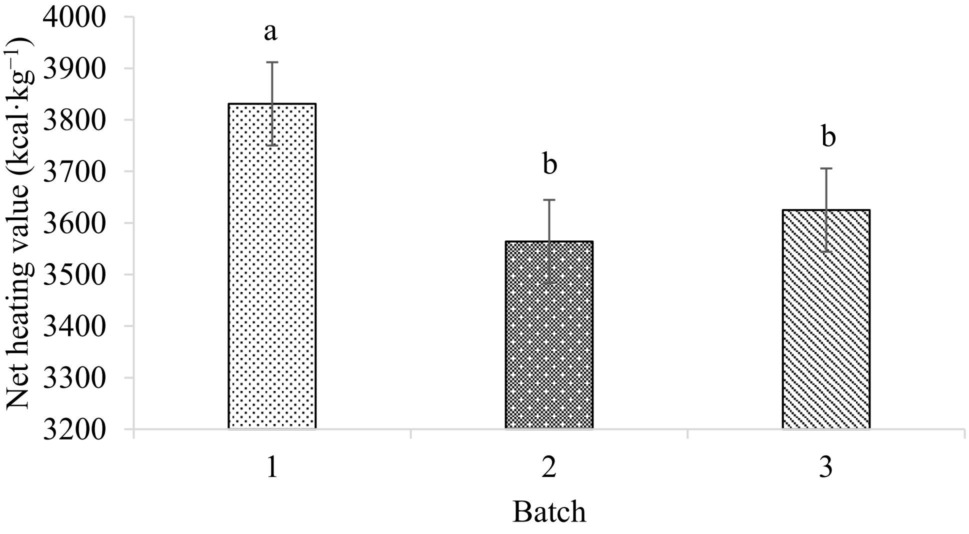

Figure 7: Net heating value (kcal·kg^{-1}) of the briquettes produced from the mixture of residues from *Pinus* sp. cutting and MDF panels (batch 1), briquettes produced from *Pinus* sp. cutting residues (batch 2), and from *Eucalyptus* spp. cutting residues (batch 3).

A study by Souza *et al*. (2012) examined the variation in higher heating value (HHV) and the influence of moisture content (wet basis) on the net heating value (NHV) of different *Pinus taeda* residues, including harvest residues, sawdust, bark, and branches. The authors observed that higher moisture content reduces NHV, since additional energy is required to evaporate water during combustion, decreasing the amount of usable energy.

In their results, sawdust showed an HHV of 4747 kcal·kg^{-1}, with 8.8% moisture content and an NHV of 4017 kcal·kg^{-1}. Branch residues, although presenting a similar HHV of 4731 kcal·kg^{-1}, had a much higher moisture content (91.81%), which led to a considerably lower NHV of 2010 kcal·kg^{-1}.

The NHV is an important parameter because it reflects the actual energy available during combustion. Moisture content has a direct effect on this value, as higher levels increase the energy demand for water evaporation. As a result, materials with lower moisture content generally provide higher NHV and better energetic efficiency.

This behavior reinforces the broader understanding that lignocellulosic residues, previously considered by-products or waste, can be effectively valorized as feedstock for energy production, offering economic benefits and potential carbon credit opportunities when used in biomass-based energy systems (Sharma *et al*., 2025; Yennuna-Konyannik and Dela-Lavie, 2025).

Conclusions

The composition of the raw material significantly influenced briquette performance, affecting both energetic and mechanical properties.

Briquettes produced from *Pinus* sp. residues showed higher energy potential, while those from *Eucalyptus* spp. presented higher density and lower friability, indicating greater mechanical stability.

Briquettes produced from a mixture of MDF and sawmill residues exhibited intermediate performance across most evaluated parameters, confirming their technical feasibility as an alternative feedstock, although without consistent advantages over conventional wood-based materials.

Overall, the results demonstrate that industrial lignocellulosic residues can be used in briquette production, but their performance depends strongly on raw material characteristics and process conditions.

From a practical standpoint, adequate control of particle size distribution and moisture content is important to ensure stable product quality and competitive performance.

Authorship contributions

G.A.S.C.: Resources, investigation, formal analysis, writing – original draft, writing – review & editing, and project administration. F.A.: Formal analysis, supervision, validation, and visualization. E.A. Formal analysis, supervision, and validation.

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Conflicts of interest

The authors declare no conflict of interest.

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