

Briquette production using chicken visceral oil and *Eucalyptus grandis* W. Hill ex Maiden versus *Pinus elliottii* Engelm. sawdust

Produção de briquetes utilizando óleo visceral de frango e serragem de *Eucalyptus grandis* W. Hill ex Maiden versus *Pinus elliottii* Engelm.

Rodrigo Mazolini Imberti^{1*}, Kelly Borne², Oswaldo Hideo Ando Junior³, Janine Carvalho Padilha¹, Leonardo da Silva Arrieche^{1,2}

ABSTRACT

The expansion of agriculture in Brazil has led to an increase in waste generation and higher energy demand. This study compares the use of sawdust residues from *Eucalyptus grandis* W. Hill ex Maiden (EG) and *Pinus elliottii* Engelm. (PE), combined with residual chicken visceral oil (CVO) from the poultry slaughtering industry, for briquette production. An initial screening, a compaction and stability test, involved producing pure sawdust briquettes under loads of 2.55 to 15.29 MPa to evaluate their post-briquetting integrity. In parallel, raw materials were characterized. The stability tests revealed that EG briquettes maintained their integrity at loads from 5.10 to 15.29 MPa, whereas PE briquettes were only stable at the highest load (15.29 MPa). Consequently, EG was selected for developing composite briquettes. TGA characterization further supported this choice, showing EG has a more favorable two-stage thermal degradation, suggesting more stable combustion than PE's single-stage profile. As expected, CVO possesses a much higher HHV (40.46 MJ/kg) than the sawdusts. While increasing CVO content boosts the briquette's energy, a processing limit was identified: oil exudation during pressing. At the maximum tested load of 15.29 MPa, the optimal formulation was found to be 20% CVO. The resulting briquette exhibited a measured HHV of 23.61 MJ/kg, representing an energy increase of over 21% compared to the pure EG briquette.

Index terms: Briquettes; energy recovery; waste; sawdust; chicken oil.

RESUMO

A expansão da agricultura no Brasil levou a um aumento no desperdício e da demanda energética. Este estudo avalia a produção de briquetes utilizando serragem de *Eucalyptus grandis* W. Hill ex Maiden (EG) e *Pinus elliottii* Engelm. (PE), combinada com óleo visceral de frango (OVF) residual. Uma triagem inicial, um Teste de Compactação e Estabilidade, envolveu a produção de briquetes de serragem pura sob cargas de 2,55 a 15,29 MPa para avaliar sua integridade pós-briquetagem. Em paralelo, as matérias-primas foram caracterizadas. Os testes de estabilidade revelaram que os briquetes de EG permaneceram íntegros em cargas de 5,10 a 15,29 MPa, ao contrário dos briquetes de PE, que se mostraram estáveis apenas na carga máxima (15,29 MPa). Consequentemente, o EG foi selecionado para o desenvolvimento de briquetes compostos. A caracterização por TGA corroborou essa escolha, mostrando que o EG possui uma degradação térmica em dois estágios, sugerindo uma combustão mais estável que o perfil de estágio único do PE. Conforme esperado, o OVF possui um PCS (40,46 MJ/kg) muito superior ao das serragens. Embora aumentar o teor de OVF eleve a energia do briquete, um limite de processo foi identificado: a exsudação do óleo. Na carga máxima testada de 15,29 MPa, a formulação ótima foi de 20% de OVF. O briquete resultante apresentou um PCS medido de 23,61 MJ/kg, representando um aumento energético de mais de 21% em comparação ao briquete de EG puro.

Termos para indexação: Briquetes; aproveitamento energético; resíduos; serragem; óleo de frango.

Introduction

Brazil generates substantial waste from its wood industry, leading to significant environmental challenges often exacerbated by inadequate technological development and waste management strategies (Silva et al., 2019). These residues, primarily sawdust and shavings from species like *Eucalyptus* and *Pinus*, possess significant energy potential but often present handling and transportation challenges in their raw form (Silva et al., 2020). This situation impedes the optimal socioeconomic and environmental utilization of wood residues, which are typically managed through combustion, pyrolysis, or organic fertilizer production, although valorization routes like adsorption (Landin-Sandoval et al., 2020) or bio-waste conversion (Karić et al., 2022) are increasingly explored.

The global focus on energy has intensified the search for alternative sources like solar, wind, hydro, and biomass. These alternatives are crucial for reducing reliance on finite fossil fuels and mitigating associated socioeconomic (employment, income, migration) and environmental problems (Dal-Bó et al., 2019).

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¹Universidade Federal da Integração Latino-Americana/UNILA, Programa de Pós-graduação Interdisciplinar em Energia e Sustentabilidade/PPGIES, Foz do Iguaçu, PR, Brasil

²Universidade Federal da Integração Latino-Americana/UNILA, Foz do Iguaçu, PR, Brasil

³Universidade Federal da Paraíba/UFPB, Centro de Energias Alternativas e Renováveis/CEAR, João Pessoa, PB, Brasil

*Corresponding author: rodrigo.mazolini@gmail.com

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Historically, agricultural residues have served as fuel, yet significant amounts are still wasted, creating environmental liabilities (Lima et al., 2019). Developing methods to utilize these residues, particularly by adding value, is essential for the generating enterprises (Borne et al., 2024). Given Brazil's vast agricultural and forestry output, biomass derived from these sector's residues, especially in the form of briquettes and pellets, represents a highly attractive energy source (Dal-Bó et al., 2019). Briquettes offer advantages such as increased energy density and reduced volume compared to raw biomass, facilitating handling and storage (Granado et al., 2021; Siyal et al., 2023).

Briquettes and pellets are produced through the densification of *in natura* or carbonized organic matter, such as wood residues, agricultural wastes like sugarcane bagasse and rice husk, or even processed wastes like hydrochar from food waste (Munir et al., 2023). This process can involve single or multiple materials, with or without binders (Karkania, Fanara & Zabaniotou, 2012). These densified fuels are commonly used in furnaces, kilns, and boilers. The primary distinction lies in size: pellets typically measure 6-16 mm in diameter and 25-30 mm in length, whereas briquettes are larger, usually 50-100 mm in diameter and 250-500 mm long (Karkania, Fanara & Zabaniotou, 2012).

Research indicates that particle size significantly impacts briquette quality, necessitating the definition of an optimal range (Gonçalves et al., 2013). Binders also influence material characteristics (Silva et al., 2019). Furthermore, incorporating diverse residues, such as mixing different lignocellulosic materials (Borne et al., 2024) or combining biomass with other wastes like poultry litter (Marreiro et al., 2024) or residual fats (Imberti, Carvalho Padilha, & Silva Arrieche, 2024), is being explored to enhance material properties and maximize biomass utilization. This study investigates the addition of chicken fat for these purposes.

Chicken fat, a byproduct of poultry processing, requires proper management due to the expanding poultry market and potential environmental impacts. While chicken fat finds applications in various sectors, including potentially cosmetics (Hermes et al., 2019) and biodiesel production (Shi, 2013), its incorporation into solid biofuels like briquettes is an emerging area aimed at valorizing this residue (Imberti, Carvalho Padilha, & Silva Arrieche, 2024),

similar to how other fatty residues like residual lubricating oil are being tested in briquette formulations (Borne et al., 2024).

Therefore, this study aims to assess the feasibility of using *Eucalyptus grandis* W. Hill ex Maiden (EG) and *Pinus elliottii* Engelm. (PE) sawdust (fine fraction, < 2.38 mm or 8 mesh) combined with residual chicken visceral oil (CVO) to produce briquettes. The goal is to add value to these residues and utilize them as a solid fuel, potentially improving logistics and economic viability.

This study aims to find an optimal balance between enhancing the energy content of sawdust briquettes with CVO and the physical processing limitations, such as oil exudation under pressure. To provide a fundamental understanding of their potential, this study includes a detailed characterization of the raw materials, including their Higher Heating Value (HHV) and their decomposition profile through Thermogravimetric Analysis (TGA).

Material and Methods

Experiments utilized sawdust and CVO sourced from companies in and around Foz do Iguaçu, PR, Brazil. All procedures were conducted at the Federal University of Latin American Integration (UNILA). To ensure material consistency and minimize experimental bias, raw materials were obtained from the same suppliers without intermediate storage between experimental stages. One raffia bag of each sawdust species (EG and PE) was donated by the 'Madeiras Brasil' sawmill, located in Foz do Iguaçu, PR, Brazil. Additionally, 50 L of chicken visceral oil (CVO) was donated by the LAR Cooperativa Agroindustrial, provided by its Poultry Industrial Unit in Matelândia, PR, Brazil. These donations provided sufficient feedstock for all formulations and replicates.

Raw material preparation

EG and PE sawdusts were collected (Figure 1 (a) and (b) respectively) and sieved using 4, 8, 16, 30, 50, and 100 mesh screens to classify particle sizes. The fine fraction passing through the 8 mesh sieve (≤ 2.38 mm) was selected for briquette production.

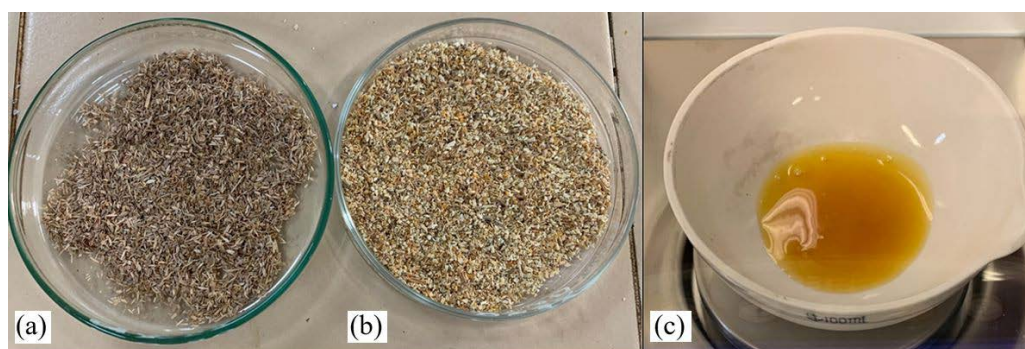


Figure 1: Raw materials (a) *Eucalyptus grandis* (EG) sawdust, (b) *Pinus elliottii* (PE) sawdust, and (c) chicken visceral oil CVO.

The CVO (Figure 1 (c)) underwent decantation at room temperature to separate oil from solid fats; the supernatant oil was collected using a pipette.

Sample characterization (Proximate Analysis)

Triplicate 3-gram samples of each sawdust type (EG and PE) were analyzed following procedures, ASTM E870-82 International (2019), and (Lees, 1982) for moisture analysis. Moisture content (M_C), volatile matter (V_M), ash content (A_C), and fixed carbon (F_C) were determined.

- Moisture Content (M_C): Samples were dried in a convection oven at 105 °C for 24 hours. Moisture content was calculated using Equation 1.

$$M_C = \frac{(m_i - m_f)}{m_i} \cdot 100 \quad (1)$$

Where m_i is the initial sample mass and m_f is the dry sample mass.

- Volatile Matter (V_M): was determined by means of an adaptation of the ASTM E870-82 standard. Samples were placed in covered crucibles and heated in an electric muffle furnace. After cooling in a desiccator, the weight loss was measured, and V_M was calculated using Equation 2.

$$V_M = \frac{(m_f - m_{FC,ash})}{m_i} \cdot 100 \quad (2)$$

Where $m_{FC,ash}$ is the mass after devolatilization (fixed carbon + ash).

- Ash Content (A_C): was determined by incinerating the samples in a muffle furnace. The procedure followed an adaptation of the ASTM D1102-84 International (2021). A_C was calculated using Equation 3 after cooling and weighing.

$$A_C = \frac{m_{ash}}{m_i} \cdot 100 \quad (3)$$

Where m_{ash} is the final ash mass.

- Fixed Carbon (F_C): FC was determined by difference using Equation 4.

$$F_C = \frac{(m_{FC,ash} - m_{ash})}{m_i} \cdot 100 = 100 - (M_C + V_M + A_C) \quad (4)$$

Higher Heating Value (HHV)

The HHV of the raw materials (EG, PE, and CVO) was determined using an IKAC2000 bomb calorimeter. Samples were

dried, and approximately 0.5 g was combusted under an oxygen atmosphere at 30 atm. The results were obtained in MJ/kg.

Thermogravimetric analysis (TGA)

The thermal behavior of the raw materials was investigated using a PerkinElmer STA-8000 TGA. Approximately 15 mg of each sample was heated from 25 °C to 700 °C at a heating rate of 5 °C/min under an oxygen atmosphere (20 mL/min). The resulting mass loss (TG) and its derivative (DTG) curves were used to identify the main stages of thermal decomposition.

Briquette production

Briquettes were produced using: (a) a 15-ton manual hydraulic press (BOVENAU, model P15500); (b) a stainless steel cylindrical mold (70 mm inner diameter); (c) a nylon piston with a stainless steel guide; and (d) a 70 mm diameter stainless steel bottom cap (Figure 2).

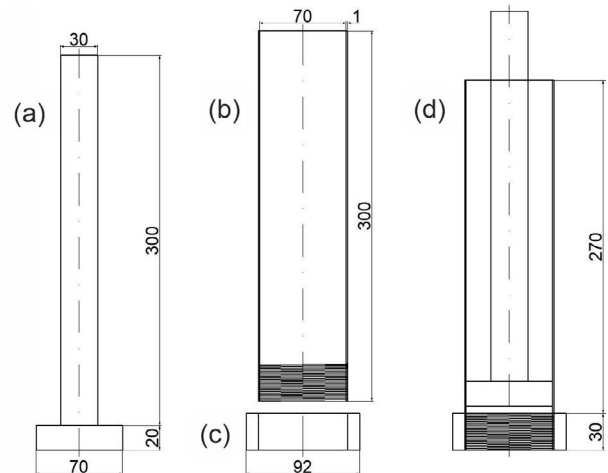


Figure 2: Benchtop briquetting machine: (a) piston; (b) cylinder; (c) base; (d) assembly.

Pure sawdust briquettes (50 g homogenized mass) were produced by applying loads of 1, 2, 3, and 6 tons (Table 1) with a 2-minute dwell time. Pressure was calculated using Equation 5.

$$P = \frac{F}{A} = \frac{Load}{\pi \cdot r^2} = \frac{Load \text{ (kgf)}}{\pi \cdot (7/2 \text{ cm})^2} \quad (5)$$

Table 1: Briquetting conditions for the 70 mm diameter mold.

Load (t)	Equivalent Force (kgf)	Pressure (kgf.cm ⁻²)	Pressure (MPa)
1	1000	25.98	2.55
2	2000	51.97	5.10
3	3000	77.95	7.64
6	6000	155.91	15.29

Based on the stability results of pure sawdust briquettes, the superior sawdust type was selected for producing composite briquettes. Mixtures containing 5% to 50% CVO by mass (total mass 50 g) were prepared. During the pressing of composite briquettes, oil exudation was visually monitored as a critical processing constraint to determine the maximum effective CVO content.

Determination of optimal briquette composition

Homogenized mixtures were pressed, observing for any oil leakage. After demolding, briquettes were weighed to assess mass loss. Thickness was measured using calipers (Figure 3).



Figure 3: Composite briquette measurement with calipers.

A mass loss tolerance of 1% was established (i.e., a final mass ≥ 49.5 g for an initial 50.0 g mixture was considered acceptable, indicating minimal oil loss during pressing).

Density determinations

Sawdust Density: Determined using a pycnometer and Equation 6.

$$d = \frac{(M2 - M1) \cdot \rho_{\text{water}}}{(M4 + M2) - (M1 + M3)} \quad (6)$$

Where M1 = pycnometer mass; M2 = pycnometer+sample mass; M3 = pycnometer + sample + water mass; M4 = pycnometer + water mass; ρ_{liquid} = specific mass of water.

- Chicken Oil Density: Determined by weighing a known volume (400 mL) of oil in a tared graduated cylinder using Equation 7.

$$d = \frac{m}{v} \quad (7)$$

- Apparent Briquette Density: Calculated using Equation 7, where mass was measured by analytical balance and volume was calculated from caliper measurements (assuming a perfect cylinder: $V = \pi \cdot r^2 \cdot h$).

Results and Discussion

Raw material characterization

Particle Size and Proximate Analysis: Raw material quality was verified; sieving confirmed minimal coarse particles (Figure 4). The fraction passing the 8 mesh sieve (< 2.38 mm) was used, as coarser material is generally unsuitable for briquetting. The particle size distribution showed that most material was finer than 8 mesh, aligning with findings by (Gonçalves et al., 2013) for *Eucalyptus grandis*, although using different sieve sets. The sawmill source provided predominantly fine sawdust, minimizing undesirable coarse fractions. The results of the proximate analysis are presented in Table 2.

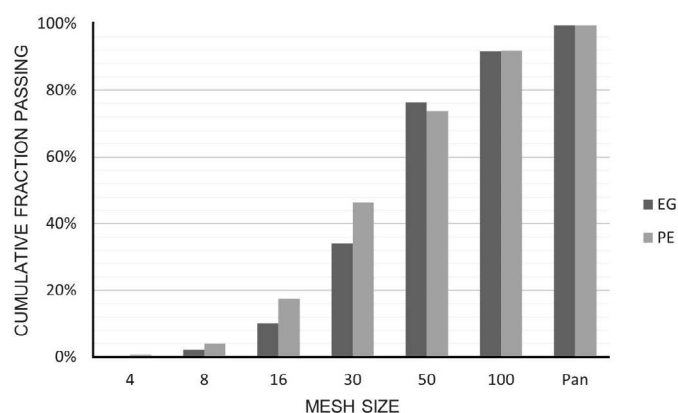


Figure 4: Cumulative particle size distribution of *Eucalyptus* and *Pinus* sawdust.

Table 2: Proximate analysis of *Eucalyptus grandis* (EG), *Pinus elliottii* (PE) sawdust and chicken visceral oil (CVO).

Analysis	<i>Eucalyptus grandis</i>	<i>Pinus elliottii</i>	CVO
Moisture content (%)	12.81 $\pm$ 0.08	17.22 $\pm$ 0.42	00.09 $\pm$ 0.10
Volatile matter (%)	64.81 $\pm$ 7.99	61.37 $\pm$ 3.25	94.67 $\pm$ 8.74
Ash content (%)	00.14 $\pm$ 0.08	00.95 $\pm$ 0.31	00.06 $\pm$ 0.07
Fixed carbon content (%)	22.24 $\pm$ 7.94	20.46 $\pm$ 3.07	5.18 $\pm$ 3.15

The proximate analysis results (Table 2) show that EG sawdust exhibited lower moisture and ash content compared to PE. The low ash content for EG (0.14%) and PE (0.95%) is a critical quality parameter, as wood sawdust typically presents values significantly lower than agricultural residues. Pereira et al. (2024) reported an ash content of 0.53% for *Pinus* sp., reinforcing the suitability of forest residues for minimizing fouling in boilers. Regarding reactivity, the higher volatile matter in EG (64.81%) compared to PE (61.37%) indicates superior ignition potential. According to Ramírez-Ramírez et al. (2021), volatile matter in *Pinus* spp. typically ranges from 82.9% to 90.7%, suggesting that the sawdust used in this study may contain a higher proportion of heartwood or has undergone specific natural oxidation prior to processing.

In contrast, the chicken visceral oil (CVO) demonstrated fundamentally different proximate characteristics, reflecting its distinct chemical composition as a lipid-based material. The CVO exhibited extremely low moisture content ($0.09 \pm 0.10\%$), achieved through decantation at room temperature to separate liquid oil from solid fats, with the supernatant oil collected via pipette. This extremely low residual moisture is critical for bomb calorimeter analysis and indicates effective separation of the oil phase. The CVO displayed the highest volatile matter ($94.67 \pm 8.74\%$) of all three materials, substantially exceeding both sawdust types and reflecting the high proportion of combustible fatty acids and their derivatives. The ash content of CVO ($0.06 \pm 0.07\%$) was the lowest of all materials tested, essentially negligible, indicating minimal mineral content and suggesting potential advantages for reducing particulate matter emissions during combustion. The fixed carbon content ($5.18 \pm 3.15\%$) was correspondingly minimal, consistent with the lipid-based composition where most combustible mass exists as volatile compounds rather than solid residue. These characteristics establish CVO as a fundamentally different energy material compared to the lignocellulosic sawdusts, functioning not merely as a binder but as a high-energy, low-ash additive to the briquette formulation.

Energy and thermal characterization of raw materials

The HHV analysis revealed a substantial energy disparity between the lignocellulosic materials and the chicken oil. The

HHV results for pure sawdust of EG (19.51 MJ/kg) and PE (19.70 MJ/kg) strongly corroborate recent literature on biomass residues in Latin America. For instance, Sette Jr. et al. (2018) reported an HHV of 19.48 MJ/kg for *Eucalyptus* wood in Brazil, a value nearly identical to that found for EG. Similarly, for the *Pinus* genus, Pereira et al. (2024) found 20.35 MJ/kg, while Zepeda-Cepeda et al. (2021) and Ramírez-Ramírez et al. (2021) reported ranges of 19.35–22.8 MJ/kg for Mexican *Pinus* species. Beyond validating feedstock quality, this high energy potential highlights the feasibility of these briquettes to replace conventional firewood, yielding socio-environmental benefits as observed by Chiang, Castro and Molina (2023). The use of CVO (40.46 MJ/kg) as a potent energy-enriching agent is thus scientifically justified by the substantial energy disparity between lipid compounds and lignocellulosic fibers. This disparity stems from the higher carbon and hydrogen content inherent in fatty acid chains, which significantly improves the briquette's energy density compared to pure wood formulations. To understand how these different chemical natures affect the combustion kinetics, a TGA analysis was conducted to investigate the thermal decomposition profile of the components, as shown in Figure 5.

The TGA confirmed the different thermal natures of the components (Figure 5). The sawdusts showed distinct profiles. For EG (Figure 5a), the two-stage degradation profile, featuring a 'shoulder' at $\sim 315^\circ\text{C}$ and a main peak at $\sim 435^\circ\text{C}$, is characteristic of sequential hemicellulose and cellulose decomposition. This is consistent with Apaydın Varol and Mutlu (2023), who identified decomposition ranges of $258\text{--}355^\circ\text{C}$ for xylose and $291\text{--}395^\circ\text{C}$ for cellulose. This two-stage profile indicates a more sequential and stable release of energy, reinforcing the choice of EG over PE for the composite briquettes. In contrast, PE (Figure 5b) presented a narrower main mass loss event around 310°C , suggesting an overlapping degradation of its components, as also reported by Pereira et al. (2024) for *Pinus* sp. sawdust. Furthermore, CVO (Figure 5c) exhibited a much broader decomposition range (approx. $200\text{--}550^\circ\text{C}$). Its complex DTG curve, with multiple overlapping peaks, corresponds to the volatilization and combustion of

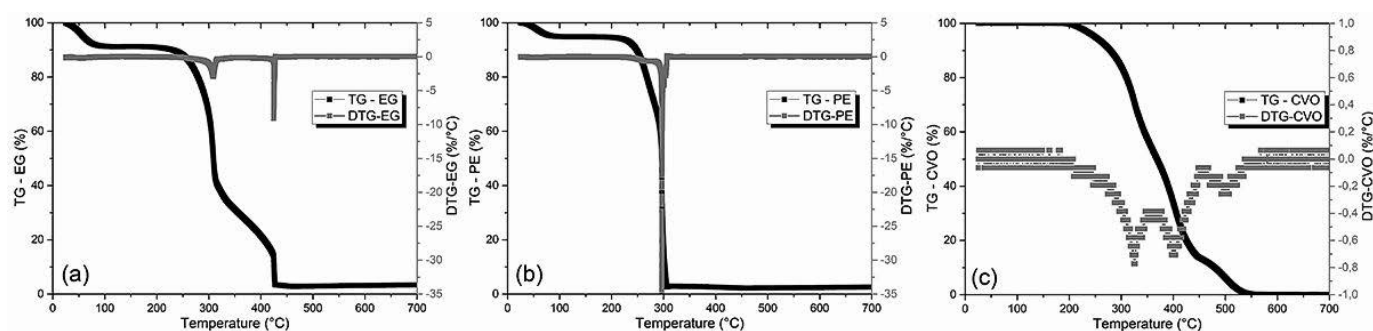


Figure 5: Thermogravimetric analysis of pure a) EG, b) PE and c) CVO.

different fatty acids. This fatty material, when incorporated into the wood matrix, alters decomposition kinetics by extending the release of volatiles, as also observed by Marreiro et al. (2024) in biomass mixtures. This suggests that incorporating CVO into the briquettes would lead to a more prolonged and stable combustion process. The final ash residue for all raw materials was low, indicating clean combustion potential.

Compaction and stability screening (material selection)

Initial compaction and stability tests were conducted on briquettes made from pure sawdust to evaluate their mechanical integrity after demolding and during storage, confirming the feasibility of briquette production, which is consistent with previous studies on PE residues (Oliveira et al., 2017). The two materials showed distinct behaviors: PE briquettes tended to disintegrate at loads of 2.55 to 7.64 MPa, only achieving acceptable integrity when pressed at 15.29 MPa. In contrast, EG briquettes were only unsatisfactory at the 2.55 MPa, meeting the integrity requirements at all higher loads.

Consequently, due to its superior performance over a wider range of pressing loads, EG sawdust was selected as the exclusive lignocellulosic base for the subsequent phase of producing and evaluating composite briquettes.

Optimization of composite EG-CVO briquettes

The addition of CVO conferred several positive characteristics to the EG briquettes, acting as an effective binder, improving cohesion between sawdust particles, and resulting in a more compact and less friable briquette. Eleven formulations with CVO contents ranging from 0% to 50% (by mass) were tested in triplicate ($n = 3$) to determine the maximum oil incorporation capacity of the sawdust matrix. Figure 6 presents the final mass of the briquettes after demolding as a function of oil content, where error bars indicate the standard deviation. A technical criterion was established to define the optimal formulation: the mass loss due to oil exudation during pressing should not exceed 1.0% of the initial mass (i.e., for a 50.0 g sample, the final mass must be ≥ 49.5 g).

As shown in Figure 6, the sawdust matrix effectively retained the CVO up to a 20% concentration. The formulation with 15% CVO exhibited the highest mass retention (49.61 ± 0.10 g). At 20% CVO, the mean mass was 49.51 ± 0.08 g, which remains strictly within the 1.0% tolerance limit. However, a significant drop occurred at 25% CVO (48.78 ± 0.36 g), indicating that the saturation point of the matrix had been exceeded, leading to substantial oil leakage under the compaction pressure of 15.29 MPa. Above 20% CVO, oil wastage becomes inefficient, a limitation consistent with subsequent studies (Imberti, Carvalho Padilha, & Silva 2024).

A linear regression analysis established the predictive equation: $HHV(MJ/kg) = 20.91 \times CVO_{fraction} + 19.51$, where $CVO_{fraction}$ is the CVO mass fraction (e.g., 20% = 0.20). This

model predicts an HHV of 19.51 MJ/kg for the pure EG briquette ($CVO_{fraction} = 0$), aligning closely with the experimental results. For the optimal formulation (20%), the model predicted an HHV of 23.69 MJ/kg. To validate this prediction, the optimal briquette was analyzed, exhibiting a measured HHV of 23.61 MJ/kg, representing an energy increase of over 21% compared to the pure EG briquette. This significant boost aligns with studies utilizing high-energy residues. For instance, Marreiro et al. (2024) achieved an HHV of up to 24.18 MJ/kg when optimizing briquettes from poultry litter and urban wood waste, attributing the high value to organic compounds in animal waste. The positive influence of lipid components on energy density is also supported by Navalta et al. (2020), who observed that rice bran with higher lipid content resulted in briquettes with superior energy properties. The experimental result confirms the model's high accuracy, with a prediction error of only 0.34%. This slight discrepancy is attributed to the minimal oil exudation (a mass loss of 0.5 g, or 1%) observed during pressing (Figure 6), which slightly reduced the final measured HHV compared to the theoretical value. This behavior aligns with findings by Navalta et al. (2020) and Marreiro et al. (2024), who noted that lipid-rich biomass improves energy properties but can lead to structural failure if the saturation limit is surpassed, yet the CVO clearly serves as a critical energy additive that enhances fuel performance beyond traditional densification limits.

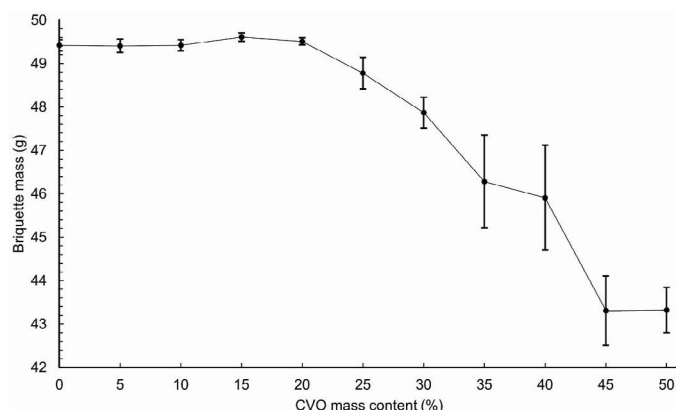


Figure 6: Final mass of EG briquettes (pressed at 15.29 MPa) as a function of CVO content. Data points represent the mean of triplicates, and error bars indicate the standard deviation.

Characterization of the optimal briquette (Density)

The density determination results were consolidated. The density of EG sawdust ($1.002 \pm 0.076 \text{ g} \cdot \text{cm}^{-3}$) was higher than that of PE ($0.725 \pm 0.067 \text{ g} \cdot \text{cm}^{-3}$), and the CVO density was determined to be $0.900 \text{ g} \cdot \text{cm}^{-3}$ (or $900 \text{ kg} \cdot \text{m}^{-3}$). The optimal briquette, composed of EG sawdust with 20% CVO and pressed at 15.29 MPa, exhibited an apparent density of $0.858 \text{ g} \cdot \text{cm}^{-3}$. This value is

consistent with densities reported for biomass briquettes produced under similar pressures (Granado et al., 2021). Densification is crucial as it significantly increases the energy density per unit volume compared to the raw biomass (Siyal et al., 2023).

Environmental and combustion considerations

The proximate analysis provides indirect evidence regarding potential combustion behavior of CVO-enriched briquettes. The negligible ash content of CVO (0.06%) incorporated into EG sawdust (0.14%) results in composite briquettes with significantly lower mineral content than pure sawdust (0.95% for PE). Low ash content typically correlates with reduced particulate matter emissions during combustion. Additionally, the extremely high volatile matter of CVO (94.67%) ensures complete liberation of combustible compounds, potentially improving combustion efficiency. Combined with the extended TGA decomposition range (200–550°C), these characteristics theoretically suggest lower peak temperatures and reduced high-temperature NO_x formation. Comprehensive combustion emission testing is necessary to validate these theoretical advantages.

Conclusions

This study demonstrates that producing briquettes from *Eucalyptus grandis* sawdust yields superior mechanical stability compared to *Pinus elliottii*. The optimal formulation, combining 20% chicken visceral oil, which acts as an efficient binder, and 80% *E. grandis* sawdust pressed at 15.29 MPa, achieved a HHV of 23.61 MJ/kg. This represents a 21% energy increase over pure wood briquettes. These results confirm the technical feasibility of valorizing agro-industrial residues into high-performance solid fuels, promoting circular economy principles and sustainable energy recovery.

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Data Availability Statement

Data available upon request to authors.

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