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WOOD RESIDUES FROM AMAZON SPECIES FOR THE PRODUCTION OF PELLETS

Antonio Alberto da Costa Neto[1], Everton Hillig[2], Marcelo José Raiol Souza[3], Jaily Kerller Batista de Andrade[4], Alexandre Techy de Almeida Garrett[5], Ezaquel Bednarczuk[6]

[1]Midwest State University - Postgraduate in Forestry Sciences - Irati, Paraná, Brazil – antoniocosneto@gmail.com
[2]Midwest State University - Teacher Dpts. Forestry Eng., Postgraduate in Forestry Sciences - Irati, Paraná, Brazil - ehillig@unicentro.br
[3]State University of Pará - Teacher Dpts. Forestry Eng. - Belém, Pará, Brazil - mraiol@yahoo.com.br
[4]Midwest State University - Postgraduate in Forestry Sciences - Irati, Paraná, Brazil - jaily.10@hotmail.com
[5]Midwest State University - Postgraduate in Forestry Sciences - Irati, Paraná, Brazil - garrettflorestal@gmail.com
[6]Midwest State University - Postgraduate in Forestry Sciences - Irati, Paraná, Brazil - eng.ezaquel@gmail.com

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Resumo

*Resíduos de madeira de espécies Amazônicas para produção de pellets***.** O objetivo do trabalho foi produzir pellets a partir de resíduos de decks e pisos e avaliar sua qualidade por meio da norma ISO 17225-2. Foram utilizados resíduos de madeira das espécies *Handroanthus serratifolius* (Vahl) S. Grose (ipê amarelo), *Hymenaea courbaril* L. (jatobá), *Manilkara elata* Huber (maçaranduba), *Dinizia excelsa* Ducke (angelim pedra), *Astronium lecointei* Ducke (muiracatiara) e *Pinus taeda* L., espécie atualmente mais utilizada na produção de pellets no Brasil. A produção dos pellets foi realizada numa peletizadora laboratorial amandus kahl modelo 14-175. Os parâmetros avaliados foram: diâmetro, comprimento, teor de umidade, densidade unitária, densidade a granel, durabilidade mecânica, teor de finos, teor de voláteis e de carbono fixo, teor de cinzas, poder calorífico superior e líquido, densidade energética. Os resultados obtidos para os 7 tipos de pellets produzidos atenderam os requisitos normativos para o uso residencial, comercial e industrial, destaque para a densidade a granel que ficou acima dos parâmetros influenciando de forma positiva na questão energética. Dentre as espécies, houve destaque na madeira do ipê amarelo, que apresentou valores de poder calorífico superior de 20.18 MG/kg, tal como o poder calorífico líquido de 17.17 MJ/kg e densidade energética de 13.93 GJ/m³.

Palavras-chave: biocombustível sólido; densidade energética; energia da madeira.

Abstract

The objective of the work was to produce pellets from deck and flooring waste and evaluate their quality using the ISO 17225-2 standard. Wood residues from the species *Handroanthus serratifolius* (Vahl) S. Grose (yellow ipe), *Hymenaea courbaril* L. (jatobá), *Manilkara elata* Huber (maçaranduba), *Dinizia excelsa* Ducke (angelim stone), *Astronium lecointei* Ducke (muiracatiara) and *Pinus taeda* L., the species currently most used in pellet production in Brazil. The production of pellets was carried out in an Amandus Kahl model 14-175 laboratory pelletizer. The parameters evaluated were diameter, length, moisture content, unit density, bulk density, mechanical durability, fines content, volatile and fixed carbon content, ash content, higher and net calorific value, and energy density. The results obtained for the 7 types of pellets produced met the regulatory requirements for residential, commercial, and industrial use, emphasizing the bulk density above the parameters positively influencing the energy issue. Among the species, there was an emphasis on yellow ipe wood, which presented higher calorific value values of 20.18 MG/kg, as well as a net calorific value of 17.17 MJ/kg and energy density of 13.93 GJ/m³.

Keywords: solid biofuel; energy density; wood energy.

INTRODUÇÃO

In the 2023 circular economy, 64% of waste generated from the process's productive areas is for energy generation. Regarding the classification of waste from the forestry sector (barks, branches, and leaves) and recycled materials together, they account for 79% of the data obtained from companies associated with the Brazilian Tree Industry (IBÁ, 2024). Reusing wood waste into energy-generating products, contributes value to the chain. In addition to industrial demand, the growth of urban centers intensifies the energy demand for fossil fuels from oil, mineral coal and natural gas reserves, considered exhaustible sources and generators of environmental degradation and pollution. Thus, the renewable energy alternative for partial or total replacement of these fuels can be wood in the form of firewood or other products with greater added value, such as charcoal, briquettes, and pellets (SILVA *et al*., 2017).

Among the main forms of compressed biomass are pellets, a solid biofuel with a diameter of 6 to 8 mm and a length that varies from 20 to 40 mm. Pellets present advantages in optimizing the burning process, less manual labor, and ease of transport. The benefits of pellets regarding natural wood are lower moisture content, higher energy density, good physical-chemical properties, and greater mechanical resistance, thus facilitating transport, storage, and handling

(HERNANDEZ *et al*., 2017).

No records were found of the production of wood pellets from the Amazon region. The moisture content varies between species and individuals, and the high density of these woods can influence the production process as well as the properties of the pellets. Another important feature is the ash content related to the emission of particulates during burning, which can reduce the calorific value. On an industrial scale, the ash content is a setback that requires maintenance to remove incrustations from its melting during combustion (GARCIA *et al*., 2018a).

Thus, this research sought to evaluate the technical feasibility of producing pellets for energy generation. The biomass comes from wood processing residues of different commercial species native to the Amazon region to meet the quality parameters required by the ISO 17225-2 Standard, whether for industrial, commercial, or residential use.

MATERIAL AND METHODS

Collection and preparation of wood processing residues.

The collection was carried out in the Metropolitan Region of Belém, a company that buys processed wood of various species to produce floors and decks. 4 kg of waste from industrialized parts of each wood were collected, totaling 20 kg of the species Angelim stone (*Hymenolobium petraeum* Ducke), Yellow ipe (*Handroanthus serratifolius* Vahl S. Grose), Maçaranduba (*Manilkara elata* Huber), Jatobá (*Hymenaea courbaril* L.) and Muiracatiara (*Astronium lecointei* Ducke). They were transferred to the municipality of Irati to carry out the analyses at the State University of the Midwest (UNICENTRO), as well as the collection of residues of *Pinus taeda* L. wood blades that served as a witness in the research.

First, the residues of the species collected in the form of chips were sent to an oven with forced air circulation at a temperature of 103+2ºC for a pre-drying period of 24 hours, as well as the apparent density, based on measurements and weighing. The leftovers were reduced into shavings in one plane and then taken to the forage crusher mill to obtain particles. Finally, sieves of 8, 10, and 12 meshes and openings of 2.36 mm, 1.7 mm, 1.40 mm,and 2.36 mm were used, respectively.

Production of pellets

The pellets were produced in an Amandus Kahl flat die laboratory pellet press, model 14-175, with a power of 3.0 kW, production capacity of 30 kg.h-1, die diameter of 6 mm, and roller rotation speed of 1200rpm. The pellet production temperature ranged from 70 to 90° C. The pellets were produced with pure wood of each species and with a mixture of the five species, in addition to using pine wood, which consisted of 7 types of pellets. Table 1 shows the types of pellets produced.

Table 1. The experimental design consisted of 5 pellets of Amazonian species, mix, and control.
Tabela 1. O desenho experimental consistiu de 5 pellets de espécies Amazônicas, mistura e controle.

Pellet type	Species
1	*Handroanthus serratifolius* (Yellow ipe)
2	*Hymenaea courbaril* (Jatobá)
3	*Manilkara elata* (Maçaranduba)
4	*Hymenolobium petraeum* (Angelim stone)
5	*Astronium lecointei* (Muiracatiara)
Mix	20% of each Amazonian species
Witness	*Pinus taeda*

Note: 20% of each Amazonian species: Angelim stone (20%) + Yellow ipe (20%) + Maçaranduba (20%) + Jatobá (20%) + Muiracatiara (20%).

After pelletizing, the pellets were conditioned in a climatic chamber at 20ºC and 65% relative humidity for one day to cool so that the physical, mechanical, chemical, and energetic properties could be analyzed, according to Table 2.

Table 2. Physical, chemical, and energetic properties for the production of pellets.
Tabela 2. Propriedades físicas, químicas e energéticas para produção de pellets.

Analyzes	Standard	Repetitions
Moisture Content	ISO 18134-2-17	3
Unit Density	ISO 17829-15	3
Bulk Density	ISO 17828-15	3

Analyzes	Standard	Repetitions
Immediate Chemistry	ASTM D1762-84	3
Higher Calorific Value	ASTM D240-17	3
Mechanical Durability	ISO 17831-1-15	3
Fines Content	ISO 18846-16	4

Note: higher calorific value (hcv). **The bulk density determination method was stereometric, using a 0.5-liter beaker filled with the pellet, and the mass of both was determined on a precision scale, the density being determined by dividing the mass of material used by the volume of the container.

To estimate the Lower Calorific Value (LCV), equation 1 was used, considering a hydrogen content of 6% (average content for wood of most forest species); in order to find the Lower Calorific Value (LCV), the procedure wasadopted (BRAND, 2010), through equation 2.

$$LCV = HCV - 600\ \frac{9H}{100} \tag{1}$$

Where: LCV = Lower Calorific Value (MJ/kg); HCV = Higher Calorific Value (MJ/kg) and H = hydrogen content (%).

$$NCV = LCV\ x\ \left[\frac{100 - W}{100}\right] - (6\ x\ W) \tag{2}$$

Where: NCV = Net Calorific Value (MJ/kg), wet basis; LCV = Lower Calorific Value (MJ/kg) than 0% moisture and W = wood moisture (MJ/kg), wet basis.

The Energy Density was calculated using Equation 3.

$$ED = \frac{BD\ X\ LCV}{1000} \tag{3}$$

Where: BD = Bulk Density (kg.m³); LCV = Lower Calorific Value (MJ/kg).

The EN Plus (2015) quality class based on the ISO 17225-2 (2014) standard for residential/commercial and industrial use was used in order to compare the quality (physical-chemical and mechanical properties) of the pellets. With the help of the Assistant 1.0 Software, the averages were compared using the Tukey test at a 5% error probability level.

RESULTS

Physical properties of wood processing waste

The wood used in this study had already been subjected to the drying process due to the production of decks and flooring with humidity control of 6% to 8%. However, the waste was disposed of in a partially covered patio, thus gaining moisture and requiring drying in an oven. After this process, the waste was conditioned in an air-conditioned room at a temperature of 20ºC and 65% relative humidity until the equilibrium humidity of the Amazon species was stabilized (Table 3).

Table 3. Mean Moisture Content (MC) and Apparent Density (AD) of the residue before pelleting.
Tabela 3. Teor Médio de Umidade (MC) e Densidade Aparente (AD) do resíduo antes da peletização.

Wood waste	MC (%)	AD (kg/m³)
Handroanthus serratifolius	9.39 a; 13.36 c.v.%	1050 ab; 12.58 c.v.%
Hymenaea courbaril	11.15 a; 8.13 c.v.%	1020 abc; 14.88 c.v.%
Manilkara elata	8.77 a; 12.21 c.v.%	1130 a; 1.86 c.v.%
Hymenolobium petraeum	11.43 a; 15.75 c.v.%	830 bcd; 16.67 c.v.%
Astronium lecointei	9.62 a; 11,01 c.v.%	750 cd; 4.36 c.v.%
Pinus taeda	8.95 a; 3.91 c.v.%	620 d; 1.61 c.v.%
Overall average	9.88	900
C.V. (%)	11.70	11.06

Notes: Means followed by the same letter in the column do not differ according to Tukey's test ($p > 0.05$). The Coefficient of Variation (C. V. %).

Pellets properties

The different types of pellets produced varied in colors (dark and light), all with a smooth texture and small cracks to a lesser extent (Figure 1). The reddish-brown coloration of Manilkara elata and the brownish-brown coloration of Handroanthus serratifolius is due to the sensory characteristics of the species (IPT, 1989a), in the same way as the other species.

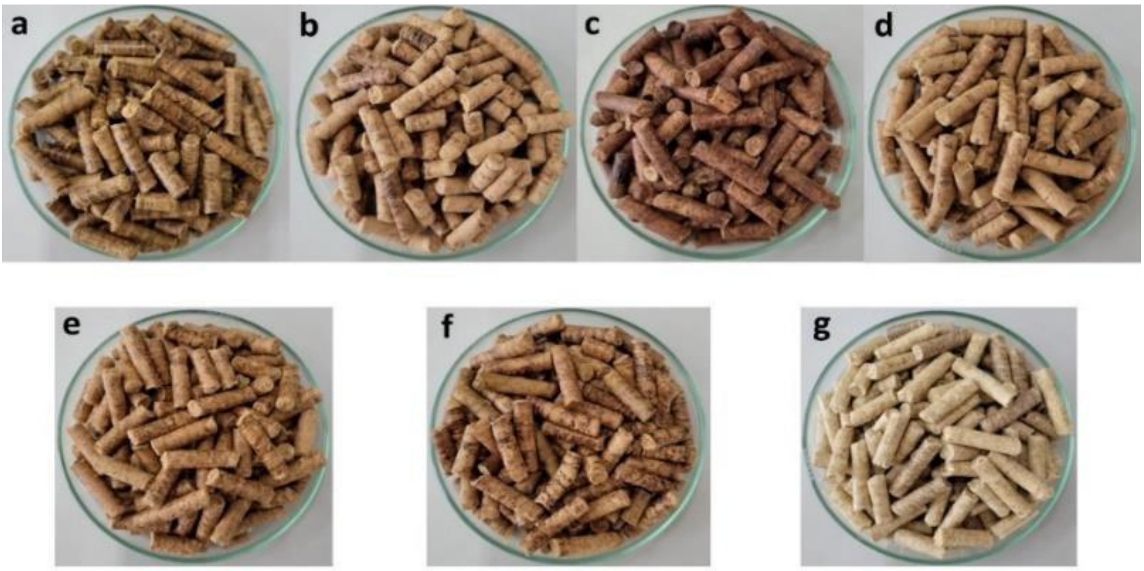

Figure 1. Pellets de *Handroanthus serratifolius* (a), *Hymenaea courbaril* (b), *Manilkara elata* (c), *Hymenolobium petraeum* (d), *Astronium lecointei* Ducke (e), Mix (f) and *Pinus taeda* (g).
Figure 1. Pellets *Handroanthus serratifolius* (a), *Hymenaea courbaril* (b), *Manilkara elata* (c), *Hymenolobium petraeum* (d), *Astronium lecointei* (e), Mix (f) e *Pinus taeda* (g).

The pellets met ISO 17225-2 Moisture Content standards ≤ 10%, except for *Hymenaea courbaril* (11.03%) and *Hymenolobium petraeum* (11.28%) (Table 4).

Table 4. Physical properties analyzed in different types of pellets.
Tabela 4. Propriedades físicas analisadas em diferentes tipos de pellets.

Pellet type	**MC (%)**	**DT (mm)**	**L (mm)**	**UD (kg.m^3)**	**BD (kg.m^3)**
Handroanthus serratifolius	7.05 cd	5.90b	26.08 a	1.31 a	723 a
Hymenaea courbaril	11.03 a	6.06 a	24.48 a	1.19 ab	676 c
Manilkara elata	7.70 c	5.98 ab	25.53 a	1.17 ab	703 b
Hymenolobium petraeum	11.28 a	6.00 ab	22.58 a	1.15 b	700 b
Astronium lecointei	9.54 b	6.08 a	25.36 a	1.30 a	670 c
Mix	9.27 b	5.96 ab	25.51 a	1.27 ab	653 d
Pinus taeda	7.04 d	5.85 b	25.08 a	1.25 ab	623 e
Overall average	8.99	5.97	24.95	1.23	678
C. V. (%)	2.62	1.54	9.27	6.56	0.72

Notes: Means followed by the same letter in the column do not differ according to Tukey's test ($p > 0.05$). Moisture Content (TU %), Diameter(DT mm), Length (CM %), Unit Density (UD kg.m^3), Bulk Density (BD kg.m^3), and the Coefficient of Variation (C. V. %).

For mechanical durability (Table 5), all types of pellets produced met the standard required by ISO 17225-2 for classification (A1), which requires ≥ 98.0, except for *Manilkara elata* pellets (97.66%) and *Pinus taeda* (97.13%), which met the standards for industrial use (I2 and I3). The fines content showed satisfactory results between 0.006 and 0.12%. The regulations require from ≤ 1.0 to ≤ 6.0.

Table 5. Mechanical properties analyzed in different types of pellets.
Tabela 5. Propriedades mecânicas analisadas em diferentes tipos de pellets.

Pellet type	DM (%)	TF (%)
Handroanthus serratifolius	99.40 a	0.05 a
Hymenaea courbaril	99.40 a	0.06 a
Manilkara elata	97.66 bc	0.11 a
Hymenolobium petraeum	98.86 ab	0.12 a
Astronium lecointei	99.06 ab	0.05 a
Mix	99.46 a	0.006 a
Pinus Taeda	97.13 c	0.02 a
Overall average	98.71	0.06
C. V. (%)	0.53	138.6

Notes: Means followed by the same letter in the column do not differ according to Tukey's test ($p > 0.05$). Mechanical durability (DM%), Fines Content (TF%), and the Coefficient of Variation (C. V. %).

The ash content is an important parameter for evaluating the quality of the pellets in relation to the immediate chemical analysis. The results found between 0.35 and 0.86% show that the pellets can be used in homes, commerce, and industry, producing the minimum amount of ash when burning biofuel, according to ISO 17225-2 (Table 6).

Table 6. Immediate analysis of different types of pellets.
Table 6. Análise imediata em diferentes tipos de pellets.

Pellet type	VC (%)	AC (%)	FCC (%)
Handroanthus serratifolius	88.21 a	0.65 abc	11.11 ab
Hymenaea courbaril	86.54 a	0.65 abc	12.81 ab
Manilkara elata	85.29 a	0.47 bc	14.22 a
Hymenolobium petraeum	87.99 a	0.35 c	11.63 ab
Astronium lecointei	85.26 a	0.86 a	13.85 ab
Mix	86.35 a	0.67 ab	12.96 ab
Pinus Taeda	88.69 a	0.62 abc	10.66 b
Overall average	86.90	0.61	12.46
C. V. (%)	1.44	18.38	10.21

Notes: Means followed by the same letter in the column do not differ according to Tukey's test ($p > 0.05$). The Volatiles Content (VC%), Ash Content (AC%), Fixed Carbon Content (FCC%), and the Coefficient of Variation (C. V. %).

The pellets' Net Calorific Value (NCV) must be ≥ 16.5 MJ.kg by the ISO 17225-2 standard. Hence, the pellets that reached the values are the *Handroanthus serratifolius* (17.17 MJ/kg) and the *Manilkara elata* (16.97 MJ/kg), while the others presented values below the norm (Table 7).

Table 7. Energy properties analyzed in different types of pellets.
Tabela 7. Propriedades energéticas analisadas em diferentes tipos de pellets.

Pellet type	HCV (MJ/kg)	NCV (MJ/kg)	ED (GJ/m³)
Handroanthus serratifolius	20.18 ab	17.17 a	13.93 a
Hymenaea courbaril	19.42 abc	15.09 d	11.89 d
Manilkara elata	20.23 a	16.97 ab	13.97 a
Hymenolobium petraeum	19.36 abc	15.05 d	12.40 cd
Astronium lecointei	19.27 bc	15.54 cd	12.90 bc
Mix	19.38 abc	15.77 cd	12.82 c

Pellet type	HCV (MJ/kg)	NCV (MJ/kg)	ED (GJ/m³)
Pinus Taeda	18.98 c	16.12 bc	13.55 ab
Overall average	19.53	15.96	13.06
C. V. (%)	1.72	1.92	1.94

Notes: Means followed by the same letter in the column do not differ according to Tukey's test ($p > 0.05$). The Higher Caloric Volue (HCV MJ/kg), Net Calorific Value (NCV MJ/kg), Energy Density (ED GJ/m³), and the Coefficient of Variation (C. V. %).

DISCUSSION

During the pelletizing process, it was necessary to humidify the particles, as the ideal humidity for the procedure should be, on average, 15%. If the material is dry enough, this can contribute to clogging of the matrix or the production of pellets with low adhesion, as humidity and temperature are important for lignin plasticization (WHITTAKER & SHIELD, 2017). We noticed a color and smooth texture variation between the different types of pellets produced (Figure 1). The reddish-brown coloration of *Manilkara elata* and the brownish-brown coloration of *Handroanthus serratifolius* are related to the sensory characteristics of these species and the others used.

According to Baumann *et al*. (2020), studying the physical properties of *Astronium lecointei* wood highlighted the influence of the presence of water in the samples' pores on the wet apparent density, which was 810 kg.m³. The dry apparent density (0% moisture) was 720 kg/m³, and the basic density was 650 kg.m³. In this research, the apparent density of muiracatiara wood was 750 kg.m³, as shown in the literature.

The pellets met the ISO 17225-2 normative standard of moisture content ≤ 10%, except for *Hymenaea courbaril* (11.03%) and *Hymenolobium petraeum* (11.28%) (Table 4). In this research, pellets from *Pinus taeda* (7.04%), *Handroanthus serratifolius* (7.05%), and *Manilkara elata* (7.70%) presented the lowest moisture contents, which can have a negative impact negative mechanical and energetic properties. In the same way, the pellets in the mix reduced humidity when compared to *Astronium lecointei* (9.54%), thus with half of the types of pellets.

In the study with wood from *Hymenolobium petraeum* through tests with heat treatment between temperature ranges (0°, 180° to 200°) and time (0.2 hours to 4 hours), checking moisture content balance between 11.28 and 11.49% for natural wood, close to that of this study with waste and pellets. Increasing the temperature and exposure time to heat treatment reduced the hygroscopic equilibrium moisture content of the wood compared to untreated wood. (FERREIRA *et al*., 2019). In the Alta Floresta region, Mato Grosso, the moisture content and wood content for flooring production were evaluated, finding values for *Hymenaea courbaril* of 14.30%; thus, when compared to pellets, knowing that it is wood, it has a high moisture content due to its physical properties and few studies on the production of pellets at the Amazon level (EVANGELISTA & COSTA, 2018).

If the desired moisture content is not reached, a new drying stage can be carried out so that the pellets reach the standard. Low humidity levels improve energy capacity, increase storage conservation, prevent the proliferation of insects and fungi, and prevent pellet degradation (GARCIA *et al*., 2013; GARCÍA *et al*., 2019).

The standard establishes values of 6±1 mm regarding diameter, with *Handroanthus serratifolius* (5.9 mm) showing a significantly larger diameter, while *Pinus taeda* (5.85 mm) had a smaller diameter. The uniformity of the diameter provides consistency in burning pellets in homes. Water vapor can influence both the increase and decrease in the diameter of the pellets, as the heating and movement of water from the center to the edges affect the union of the particles during pelletization (FARIA *et al*., 2016).

According to Table 4, the length of all pellets produced in this study met ISO 17225-2, which requires 3.15 to 40 mm, highlighting *Handroanthus serratifolius* (26.08 mm). It was found that the pellets from the mix (25.51 mm) increased the length in the study, even down to the smallest in size of the pellets of *Hymenolobium petraeum* (22.58 mm). It is stated that if the length of the pellets is small, it can compromise the mechanical durability and increase the fines (AKDENIZ *et al.*, 2017).

The apparent unit density of the pellets, although not a requirement of the standard, is an evaluation parameter, with values varying from 1.19 kg.m³ and a maximum of 1.31 kg.m³, showing that the pelletization process favored increased densification (JACINTO *et al*., 2017). Regarding apparent density, all pellets produced in this research met ISO 17225-2, with emphasis on *Handroanthus serratifolius* (723 kg.m³), *Manilkara elata* (703 kg.m³) and *Hymenolobium petraeum* (700 kg.m³). Bulk density is one of the criteria used to evaluate pellets, which makes them granulated and cylindrical and facilitates storage and packaging, favoring storage and transport logistics (GARCIA *et al*., 2018a).

Regarding the correlation, pellets' moisture content and bulk density are inversely proportional. This means that as the moisture content increases, the bulk density of the pellets tends to decrease. Much of the Amazonian wood has a high apparent density, and this is reflected in the properties of the pellets, with bulk density and low moisture content, meaning smaller spaces for water to occupy, as evidenced in the results of *Handroanthus serratifolius* and *Manilkara elata*. However, also with *Hymenolobium petraeum*, despite the moisture content exceeding 1.28% that ISO 17225-2 requires, it did not compromise the density already that the wood of this species has a high density.

Regarding mechanical durability (Table 5), all types of pellets produced met the standard required by ISO 17225-2 for classification (A1), which requires ≥ 98.0. However, *Manilkara elata* (97.66%) and *Pinus taeda* (97.13%) did not reach this standard, but they still fit the criteria for industrial use (I2 and I3). The fines content was satisfactory, ranging from 0.006 to 0.12%, whereas the standard requires ≤ 1.0 to ≤ 6.0. Mechanical durability is a test that evaluates the resistance of pellets, considered solid biofuels, concerning handling, transport, and movement of loads along the road; in addition to helping to estimate the amount of fines generated, the smaller the amount, the greater the durability (BRAND *et al*., 2018).

In the immediate chemical analysis, the ash content as an evaluation parameter met the ISO 17225-2 normative standard for pellet quality. The results, which range from 0.35 to 0.86%, indicate that the pellets are suitable for use in homes, commerce, and industry, resulting in a minimum amount of ash during the burning of the biofuel (Table 6). Knowing the ash content of the raw material used in pellet production helps prevent problems such as deterioration, crust formation, and the need for frequent burner maintenance. These factors can increase costs in the production chain and affect energy efficiency, as the presence of mineral substances in the ash can reduce ignition performance (PROTÁSIO *et al*., 2015).

In this research, the fixed carbon content varied between 10.66% for *Pinus taeda* and 14.22% for *Manilkara elata*. The content of volatile materials was 88.68% and 85.29%, respectively. The ISO 17225-2 standard requires that pellets' Net Calorific Value (NCV) is at least ≥ 16.5 MJ/kg. The pellets that met this criterion were *Handroanthus serratifolius* (17.17 MJ/kg) and *Manilkara elata* (16.97 MJ/kg). The other pellets presented values below the normative standard (Table 7). Regarding energy density, values ranged from 11.89 GJ/m³ for *Hymenaea courbaril* to 13.97 GJ/m³ for *Manilkara elata*. According to Pereira *et al*. (2016), the densification procedure favors the increase in the energy density of the pellet, thus influencing the mass and volume relationship and correlated with the apparent.

As for energy density, the results ranged from 11.89 GJ/m³ for *Hymenaea courbaril* to 13.97 GJ/m³ for *Manilkara elata*. According to Pereira *et al*. (2016), the densification process contributes to increasing the energy density of the pellet, being influenced by the mass and volume ratio, and being correlated with the bulk density. For Higher Calorific Volue (HCV), the pellets analyzed in this research demonstrated excellent efficiency among lignocellulosic content. In this context, *Manilkara elata* (20.23 MJ/kg) and *Handroanthus serratifolius* (20.18 MJ/kg) stood out, while *Pinus taeda* (18.98 MJ/kg) obtained a lower value.

By correlating the physical properties and the pellets produced, the pelletizing and drying process decreased the moisture content, affirming and contributing to the performance of the Net Calorific Value (NCV) for the *Handroanthus serratifolius* and *Manilkara elata* pellets.

CONCLUSIONS

- The research met the proposed objective by analyzing physical, mechanical, chemical, and energetic properties. Thus, demonstrating options for using residues from commercial Amazonian species when producing pellets and corresponding to the quality requirements established by ISO 17225-2, they meet the needs of industrial, commercial, or residential use.
- Based on the analyses carried out, *Handroanthus serratifolius* stood out with a lower moisture content, favoring its energy properties, as well as the quality and size of the pellets, as well as the unitary and apparent densities, thus having a smaller volume and greater energy density, as well as *Manilkara elata*, thus demonstrating advantages in marketing when compared to other species.
- Regarding mechanical durability, which results in pellets that are resistant to transportation and handling, we have *Handroanthus serratifolius* and *Hymenaea courbaril*, as the Mix generates a lower fines content, thus demonstrating that they are useful for transportation and handling.
- All pellets met the low ash content standard according to ISO 17225-2, highlighting *Hymenolobium petraeum*, which reduces the fouling of industrial machines that use pellets for burning and generating energy.
- However, using wood processing waste from Amazonian species to produce pellets shows energy alternatives. It is enough to study the species characteristics and properties and use the analysis and evaluation standards according to ISO 17225-2.

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