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QUALITY OF CHIPS PRODUCED FOR ENERGY PURPOSES IN SOUTHWESTERN PARANÁ

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Resumo

Qualidade dos cavacos produzidos para fins energéticos na região Sudoeste do Paraná. Para caracterização e monitoramento do teor de umidade da biomassa energética utilizada por uma indústria do ramo alimentício no sudoeste do Paraná, foram analisados materiais de cinco fornecedores diferentes, sendo quatro de *Eucalyptus* spp. e um de *Pinus* sp. Os cavacos foram caracterizados de acordo com o teor de umidade na base úmida, densidade aparente, poder calorífico e análise química imediata. Com os dados coletados, geraram-se curvas de calibração para ajuste do equipamento de medição do teor de umidade (MUG M75) utilizado pela empresa. A calibração do M75 foi feita com base em modelo regressão linear e todos os cavacos apresentaram uma curva de calibração adequada com um coeficiente de determinação (R^2) acima de 0,9. Os cavacos apresentaram teor de umidade entre 35 e 45% na base úmida. O maior valor de densidade aparente foi de 207,67 kg/m³. O poder calorífico superior foi estatisticamente igual para todos os materiais, com média de 4.384,4 kcal/kg. Em relação a análise química imediata, os materiais voláteis tiveram teor entre 80 e 84% e, para o carbono fixo, o maior valor obtido foi 19,16%. Os cavacos estudados apresentaram baixos teores de cinzas, a média geral foi de 0,59%. Todas as curvas de calibração apresentaram alta precisão (> 90%), mostrando que o método usado pode substituir a secagem em estufa, após a receita ser calibrada para os fornecedores.
Palavras-chave: biomassa florestal, medidor portátil, poder calorífico.

Abstract

Quality of wood chips produced for energy purposes in the southeast region of Paraná. To characterize and monitor the moisture content of the energy biomass used by a food industry in southwestern Paraná-Brazil, the materials of five different providers were analyzed, four were from *Eucalyptus* spp. and one from *Pinus* sp. The chips were characterized according to the moisture content on a wet basis, apparent density, calorific value and immediate chemical analysis was performed. With the collected data, calibration curves were generated to adjust the moisture content measurement equipment, MUG M75, used by the company. The calibration of the M75 was made based on the linear regression model, and all chips presented an adequate calibration curve with a coefficient of determination (R^2) above 0.9. The chips had a moisture content of 35 to 45% in the humid base. The highest value of apparent density was 207.67 kg.m³. The superior calorific value was statistically equal for all materials, with an average of 4,384.4 kcal/kg. Regarding the immediate chemical analysis, volatiles were between 80 and 84%, for fixed carbon the highest value obtained was 19.16%. The studied chips had low ash contents, with a general average of 0.59%. All calibration curves showed high accuracy (> 90%), showing that the method used can replace oven drying after the recipe is calibrated for suppliers.
Keywords: forest biomass, portable meter, calorific value.

INTRODUCTION

Nowadays, energy production is an undeniable necessity, as the demand for fuel, especially in the industrial sector, is growing. For this reason, promoting the diversification of the energy matrix has become a worldwide trend. Brazil has one of the best electricity matrices with renewable energy sources in the world, accounting for 83% of the Brazilian electricity matrix, with hydroelectric plants as the main generating source. Biomass, the focus of this study, is the third largest energy source for generation from renewable sources, with an 8.9% share of the sector (GOVERNO DO BRASIL, 2021).

Given the country's great forestry potential, the greater use of forest biomass for energy generation still faces some challenges. Electricity production from forest biomass is limited in Brazil and is mostly used in self-propelled plants, i.e. companies that have electricity cogeneration systems. In this case, the main biomass used is sugarcane bagasse (77%), used especially in sugar and alcohol milling companies, followed by black liquor (18%) primarily used in pulp and paper mills and, to a lesser extent, wood waste (5%), used in a wide range of industries (COGEN, 2021).

When wood is used as fuel, the material is used for energy end-use through conversion processes, using simple thermochemical transformation technological routes, such as direct combustion and carbonization (NOGUEIRA; LORA, 2002). Firewood and chips are examples of these processes.

Widely used in the energy sector, wood chips can come from different forest species, or even waste from forestry operations, sawmills, or wood processing units (AMORIM, 2021). In Brazil, species of the genus *Eucalyptus* sp. are the main species used as forest energy biomass, due to their high productivity. Widely used in the energy sector, wood chips can come from different forest species, or even waste from forestry operations, sawmills, or wood processing units (AMORIM, 2021). In Brazil, species of the genus *Eucalyptus* sp. are the main species used as forest energy biomass, due to their high productivity.

However, the widespread use of biomass for energy purposes in industries depends on a careful assessment of its quality, given the significant changes in the physical and chemical properties of the material as a result of the management applied to it, especially in terms of moisture content, ash content, and heating value (FURTADO *et al.*, 2012). It is therefore necessary to know how to characterize and control the variation in these properties to optimize the biomass produced for energy purposes.

In terms of forest biomass, with the majority of woody material from species of the *Pinus* and *Eucalyptus* genera being used, attention must be paid, above all, to the moisture content of the material to be used, as this is a determining factor in the generation of net heating value, which effectively generates the energy to be used in industrial processes. In addition, factors such as the basic specific mass, which is related to the genetic material in use and the management of the plantations, are another factor of great importance. The fixed carbon content, volatile materials, lignin content, and ash content also affect the quality of forest biomass.

Research results, even for *Eucalyptus* and *Pinus* genetic materials, vary depending on other factors such as the juvenility of the materials (FERREIRA *et al.*, 2017), different species (DIAS Jr. *et al.*, 2016), the origin of the material, such as sawmill waste (SOUZA *et al.*, 2022), water and nutritional availability (SILVA *et al.*, 2019), among other aspects.

This study was carried out to assess the quality of forest biomass used for energy purposes in the food industry in the southwest region of Paraná, through the characterization and instantaneous determination of the moisture content and apparent density of the chips produced.

MATERIAL AND METHODS

Study location

The Southwest of Paraná is a mesoregion resulting from the subdivision of the state with an area of approximately 11,638 km² located on the Third Plateau of Paraná, occupying around 6% of the state's territory with 42 municipalities and 658,865 inhabitants and, in its border regions are the state of Santa Catarina to the south and Argentina to the west with the Iguaçu River, which is its most important geographical boundary, directly influencing aspects such as trade and tourism (IBGE, 2022). According to Santos *et al.* (2018), the predominant soils are well-drained Alfisol, Red Latosols, Litholic Neosols and Nitosols.

The climate of the region under study is classified as subtropical type Cfa, according to the Köppen classification, with an average annual rainfall of 1,800 to 2,000 mm and an average annual temperature of 19 °C, at an altitude of 530 m (ALVARES *et al.*, 2013). Its economy revolves around agro-industry with the production of grains (soy, corn, and wheat) and poultry. Industrial activity also stands out with the production of durable and non-durable consumer goods such as petrochemicals, wood, paper, and cellulose (IBGE, 2022).

Sample collection and preparation

The experiment was carried out with chips from four *Eucalyptus* spp. and one *Pinus* sp. material used for energy production in a food industry located in the southwest region of Paraná (Table 1).

Table 1. Description of the materials used in the experiment.
Tabela 1. Descrição dos materiais utilizados no experimento.

Supplier	Material	Origin
1	*Eucalyptus* spp.	Stem
2	*Eucalyptus* spp.	Sawmill waste
3	*Eucalyptus* spp.	Stem
4	*Eucalyptus* spp.	Whole tree
5	*Pinus* sp.	Sawmill waste

Two samples were taken from each supplier. For the first collection, a load of chips was randomly selected from each supplier and four samples of approximately 200 g were taken, to characterize and determine the moisture content of the material when it arrived at the industrial yard. For the second collection, four samples totaling approximately 30 kg of chips were taken from the same load to generate the calibration curves used to adjust the measuring bucket (MUG M-75).

All the material collected in the chip piles from each supplier contained bark, although the materials from suppliers 1 and 3, being from shaft had a lower proportion of fines (around 1-2% of particles < 3 mm in length) and a more regular particle size composition, most of them with medium to common chips (16-25 mm in length). Particle size variability increased slightly for supplier 4 (2-3% fines up to 63 mm in length), as it also included the branch fraction, and even more so for the material from suppliers 2 and 5, as they were sawmill residues, with material of various sizes, from fines (4-5%, < 3 mm in length) to large chips (25 mm - 63 mm in length), with these two suppliers having the most irregular material sizes. Even so, all the materials studied met the classification set out by Lippel (2024).

The material was collected and analyzed from July to October 2020, during the winter/spring period. The climatic variables for October were 65.7% average relative humidity, ranging from a minimum of 21.5% to a maximum of 92.5%. According to the Weather Station of UTFPR, in this period, the minimum temperature was 22.1ºC and the maximum 25.5ºC and the average monthly temperature was 22.1 ºC and accumulated rainfall was 86.8 mm.

Evaluated properties

The moisture content was obtained using the methodology described in NBR 14929:2017 (ABNT, 2017). The samples were prepared by NBR 14660:2004 (ABNT, 2004), and two replicates were carried out in duplicate for each supplier. The values for moisture content were calculated using the equation below.

$$TU = [((M1 - M2))/M1] \times 100 \; [\%]$$

where: TU is the moisture content (%), M1 is the wet mass of the sample (g), and M2 is the oven-dried mass at 105 ± 2 ºC (g).

The apparent density was obtained from the ratio between the weight of the material and the volume of the container, by NBR 14984:2003 (ABNT, 2003), and 3 repetitions were carried out for each supplier. From the basic density and higher calorific value, it was possible to determine the energy density of the chips.

Higher heating values were determined using an adiabatic calorimetric pump, by NBR 8633:1984 (ABNT, 1984). The values for lower calorific value and net calorific value were calculated using the equations below.

$$PCI = PCS - Qw \;\; [kcal/kg]$$

where: PCI is the lower heating value, PCS is the higher heating value, and QW is the heat of condensation of water vapor (6%).

$$PCL = PCI \, [(100 - W)/\, 100] - (6 \times W) \;\; [Kcal/Kg]$$

where: PCL is the net heating value, PCI is the lower heating value, and W is the % moisture in the fuel on a wet basis.

The immediate chemical analysis was obtained using the methodology proposed by ASTM. D1762: Standard Test Method for Chemical Analysis of Wood Charcoal. The time of the complete carbonization test, for analysis of the ash content, was 6 hours. For both analyses, the material was crushed and sieved, then placed in an oven to dry completely. A muffle furnace heated to 950 °C was used to determine the volatile material. The samples were sieved, using the material retained on the 60 mesh sieve, placed in covered crucibles, and taken first to the muffle furnace door for 2 minutes for acclimatization, then to the edge of the muffle furnace with the door still open, for 3 minutes, then placed in the bottom of the muffle furnace, with the door closed, for 6 minutes, remaining for 60 minutes to cool for weighing. The amount of volatile material present in each sample was obtained using the equation below.

$$MV = [(M1 - M2)/M1] * 100 \;\; [\%]$$

where: MV is the volatile material, M1 is the crucible mass + sample mass before going into the muffle furnace (g), and M2 is the crucible mass + sample mass after being taken out of the muffle furnace (g).

To determine the ash content, the muffle furnace was heated to 750ºC. The samples remained in covered crucibles, which were first taken to the muffle furnace door for 2 minutes for acclimatization. The samples were then placed on the edge of the muffle furnace with the door still open for 3 minutes and then on the bottom of the muffle furnace with the door closed for 6 hours. After removing the samples from the muffle furnace, they were placed in the desiccator and left to cool for about 60 minutes for weighing. The ash content was obtained using the equation below.

$$Ash\ content = (M3/M1) \times 100\ [\%]$$

where: M1 the crucible mass + sample mass before going into the muffle furnace (g) and M3 the crucible mass + ash mass (g).

The percentage of fixed carbon in the materials sampled was obtained from the volatile material content and the ash content, as shown in the equation below.

$$CF = 100 - (MV + M3)[\%]$$

where: CF is the fixed carbon, MV is the volatile material (%), and M3 the crucible mass + ash mass (g).

To determine the instantaneous moisture content, the Marrari MUG - M75 moisture meter for biomass and granules was used, which requires the creation of a data set relating dielectric interference and moisture for calibration.

Initially, a calibration curve was programmed to determine humidity using a simple regression model, where the independent variable is the number of bits read by the capacitive sensor and the dependent variable is humidity (MARRARI, 2019). The previously collected material was then dumped on plastic tarpaulins, duly separated and identified, and exposed to the open air for approximately 8 hours a day for 20 days.

Every two days, daily readings were taken of the number of bits given by the equipment, for a total of 10 readings. Two samples of 200 g each were then taken from the top and bottom of the material stored in the equipment to determine the moisture content using the gravimetric method proposed by NBR 14929:2017 (ABNT, 2017). Analysis of variance and mean comparison tests were carried out between the values of the treatments tested (suppliers/material). The model was adjusted using Excel 2016® software. The calibration curve was generated using Tracker® software.

RESULTS

Chip characteristics

The data on the energy and chemical properties evaluated are shown in Tables 2 and 3. Moisture content and calorific value showed no statistically significant difference between the materials, but the density of the stem-sourced chips was higher than the other materials, with sawmill residues and whole-tree material having the lowest values.

Table 2. Comparison of mean values for moisture content (TU%), apparently density (Dens.), superior calorific value (PCS), lower calorific value (PCI) and net calorific value (PCL) in different wood chips available.
Tabela 2. Comparação de médias para teor de umidade (TU%) em base úmida, densidade aparente (Dens.), poder calorífico superior (PCS), poder calorífico inferior (PCI) e poder calorífico líquido (PCL), dos diferentes cavacos avaliados.

Supplier / Material	Genus	TU% (Ubu)	Dens. (kg/m³)	PCS (kcal/kg)	PCI (kcal/kg)	PCL (kcal/kg)
1. Stem	*Eucalyptus*	36.67 ns	188.24 (b)*	4,348 ns	4,025	2,329.0
2. Sawmill waste	*Eucalyptus*	39.93 ns	173.39 (d)	4,362 ns	4,136	2,244.9
3. Stem	*Eucalyptus*	37.69 ns	207.67 (a)	4,376 ns	4,087	2,320.9
4. Whole tree	*Eucalyptus*	42.38 ns	178.22 (dc)	4,315 ns	4,035	2,073.5
5. Sawmill waste	*Pinus*	42.64 ns	182.98 (bc)	4,521 ns	4,260	2,187.7
Overall Average	-	39.9	186.1	4,384.4	4,108.6	2,231.2
Coef. of Variation (%)	-	6.75	7.12	1.82	2.33	4.73

* Averages followed by the same letter in the column do not differ statistically at the 5% probability of error level using the Tukey test; ns: non-significant difference at the 5% error level.

The chemical analysis of the chip material showed significant differences between them. The percentage of volatiles was higher in the *Eucalyptus* stem from supplier 1, with the *Eucalyptus* and *Pinus* sawmill residues, as well as the stem material from supplier 3 showing intermediate values, with the lowest value in the *Eucalyptus* whole tree material.

The ash content was higher in the stem material from supplier 3, and was statistically similar for all the others, despite the greater variability in the data between the materials. Fixed carbon was higher in *Eucalyptus* whole-tree material, followed by *Pinus* sawmill residues and the other materials with lower values (*Eucalyptus* stems and sawmill residues).

Table 3. Proximate analysis of the five wood chips. Means followed by different letters differed by the Tukey test at 5% significance.
Tabela 3. Análise química imediata dos cinco tipos de cavacos oriundos de diferentes origens de material na região Sudoeste do Paraná.

Supplier / Material	Gender	Volatile (%)	Ashes (%)	Fixed Carbon (%)
1. Shaft	*Eucalyptus*	84.57 a*	0.50 b	14.92 d
2. Sawmill waste	*Eucalyptus*	82.85 b	0.27 b	16.88 c
3. Shaft	*Eucalyptus*	82.50 b	0.79 a	16.70 c
4. Whole tree	*Eucalyptus*	80.74 c	0.41 b	19.16 a
5. Sawmill waste	*Pinus*	82.13 b	0.52 b	17.35 b
Overall Average	-	82.60	0.50	17.00
Coef. of Variation (%)	-	1.67	38.30	8.93

* Averages followed by different letters in the column differed by the Tukey test at 5% significance.

Calibration curve

Figure 1 shows the drying curve for the chips from the different suppliers studied, and Tables 4 and 5 show the relationship between the sensor reading in bits and the humidity for the chips evaluated. Calibration curve 6 was drawn up based on data from suppliers 1, 2 and 4, with a good correlation, since it was based on materials of the same origin and similar constitution.

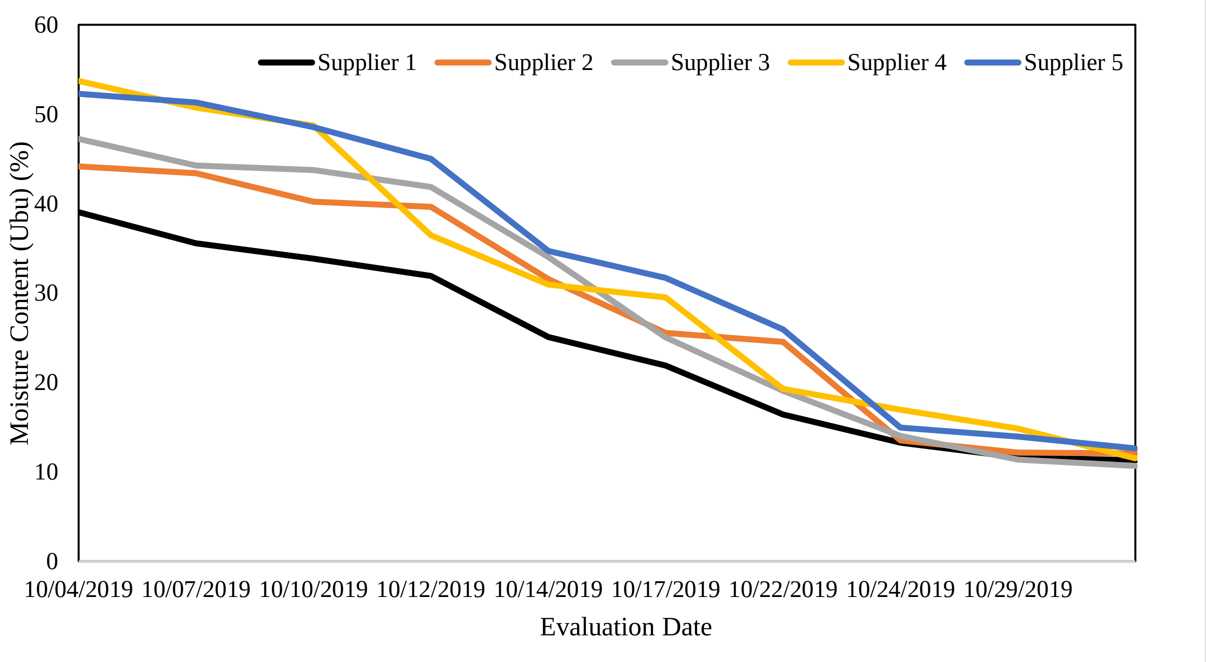

Figure 1. Drying curve, the different wood chips evaluated.
Figura 1. Curva de secagem dos diferentes cavacos avaliados.

Table 4: Relationship between the number of bits and the moisture content (U%) of suppliers 1, 2, and 3.
Tabela 4. Relação entre o número de bits e o teor de umidade (U%) dos fornecedores 1, 2 e 3.

Points	**Calibration curve 1**		**Calibration curve 2**		**Calibration curve 3**	
	Bits	U%	*Bits*	U%	*Bits*	U%
1	2,000	0.0	2,000	0.0	2,000	0.0
2	10,864	11.1	11,763	11.5	11,978	10.0
3	15,224	17.1	16,300	18.0	16,846	13.0
4	19,623	25.0	20,835	27.4	21,714	19.8
5	24,007	37.8	25,375	41.7	26,582	38.0

Table 5. Relation between the number of bits and the moisture content (U%) of suppliers 4, 5 and additional calibration curve 6.
Tabela 5. Relação entre o número de bits e o teor de umidade (U%) dos fornecedores 4, 5 e curva e calibração adicional 6.

Points	**Calibration curve 4**		**Calibration curve 5**		**Calibration curve 6**	
	Bits	U%	*Bits*	*Bits*	U%	*Bits*
1	2,000	0.0	2,000	0.0	2,000	0.0
2	11,656	10.3	11,656	12.7	11,956	10.8
3	16,186	21.1	16,186	22.1	17,428	20.5
4	20,717	34.0	20,717	32.6	22,899	32.8
5	25,248	43.2	25,248	42.7	28,370	45.3

As a result of the data analysis, it was possible to create equations relating the collected moisture content values and the number of bits, as well as their respective coefficients of determination (R^2) (Table 6).

Table 6. Determination coefficients (R^2) of the linear equations generated for the calibration curve.
Tabela 6. Coeficientes de determinação (R^2) das equações lineares geradas para curva de calibração.

Calibration curves	Coefficients		R^2
	β_0	β_1	
1	0.0018	- 7.5344	0.9613
2	0.0019	- 8.9773	0.9662
3	0.0015	- 7.4006	0.9212
4	0.0018	- 9.7966	0.9317
5	0.0021	- 10.217	0.9090
6	0.0019	- 9.5018	0.9478

DISCUSSION

Evaluating the quality characteristics of the chips supplied to companies is fundamental, as it provides subsidies to promote the efficiency of the species' energy potential, as well as their feasibility of use (SOUZA *et al.*, 2021) and greater use of the load to be handled, stored and transported (MARRARI, 2019) for later use in the industry.

The percentage moisture content values obtained for the materials are within the range in which chips are normally sold in the region, from 35 to 45% moisture on a wet basis. However, as described by GARSTANG *et al.* (2002), for the best efficiency of forest biomass used for energy generation, the material must have a moisture content of 30% or less. By monitoring the moisture content on a load-by-load basis, greater control can be achieved and bonuses can even be given to suppliers who present drier material, as there is a gain in biomass burning efficiency, with an increase in PCL values.

When a certain material has a high moisture content, it needs to be dried before the initial burning phase, but this process requires energy, which increases the cost of the generation process. According to Brand (2012), there is a significant variation in humidity about the time and form of storage of the material, and there may be gains in calorific value.

It is noticeable that there is a standardization (similarity) of the moisture values between the materials, which is related to the fact that the material was harvested and processed at a time when the weather conditions were similar, both in the field and in the yard. This leads to similar moisture levels between the materials, which are still a little higher than the ideal, which would be less than 30%.

Balista (2023), when studying different storage conditions (open yard and covered yard) for *Eucalyptus* spp. chips found that the dry basis humidity can be reduced by up to 73% when in a covered yard, with a more satisfactory calorific value. About the bulk density of the chips evaluated, Supplier 3 had a significantly higher value than the others. The two highest apparent chip density values presented by Suppliers 3 and 1 refer to materials whose chips come only from tree stems, with a predominance of woody material, which has a higher density.

All PCS values were similar between suppliers. Similar results were obtained by Brun *et al.* (2018) when characterizing the energy properties of different Eucalyptus sp. genetic materials from an experimental test located on the experimental farm of the Federal Technological University of Paraná, in southwestern Paraná, who obtained an average PCS of 4,464.00 kcal/kg.

PCL is the amount of energy that is released and can be used in a cogeneration system. In the study, PCL was determined by the moisture content at which the material arrived at the industry's stockyard. Suppliers 1, 2, and 3 had higher PCL values

By relating the PCL information to the apparent density of the material, the energy density (kcal/m³) of the chips used can be obtained. As all the materials are homogenized in the industrial yard and the moisture content of the material at the time it enters the boiler system is unknown, the energy density was calculated using the average values of the bulk density and the PCL, and in this case, each cubic meter of chips will release 415,227.44 Kcal.

Regarding volatile material, the expected chip values for the species considered are 80% to 86% for *Eucalyptus* sp. (SANTOS *et al.*, 2019; BRUN *et al.* 2018) and 74% to 82% for *Pinus* sp. (SANTOS *et al.*, 2019). All the suppliers showed values within the indicated ranges, with supplier 1 standing out. This result can be explained by comparing it with the value of fixed carbon, the lowest result obtained in the study, since, according to these authors, the contents of volatile materials and fixed carbon are inversely proportional. Thus, based on knowledge of the volatile material content of a combustible material, we can estimate its combustion potential, i.e. fuels with low fixed carbon values and a high volatile material index will burn more quickly.

The overall average fixed carbon values (17%) were obtained for the chips highlighted in supplier 4, with the highest value and, consequently, the lowest volatile material content. The ash content of the chips analyzed can be considered low, a factor that supports the indication of these materials for use in energy generation.

About the process of creating the drying curve, figure 1 shows that good results were obtained, with a high correlation between the variables, as shown in Tables 4 and 5. The high R^2 values allowed the moisture content of the wood to be calculated from its dielectric property with a high degree of reliability. In a study carried out by Jensen (2006) using other dielectric meters on coniferous and hardwood biomass, R^2 values of over 90% were also obtained.

CONCLUSION

- All the materials analyzed had physical, chemical, and energy properties within average standards, allowing them to be used for energy purposes efficiently and sustainably, without any significant differences between them;
- The moisture content of the materials evaluated is within the region's marketing standards, but outside the recommended content for more efficient use;
- The ash content, one of the most important components of biomass for energy use, showed values within the technically recommended range for chips;
- The higher calorific value was statistically the same for all the chips analyzed;
- The calibration curves generated are efficient, due to the high coefficient of determination, determining equations for use in measuring equipment with values above 0.9 (R^2), allowing good estimation of the moisture calculated from the gravimetric method;
- The equipment used to determine moisture proved to be efficient, even for chips with moisture above the fiber saturation point, showing that it is possible to determine moisture instantaneously;
- Each material has its regression curve and is differentiated by the density and granulometry of the material, as well as characteristics of each sample such as the presence or absence of bark. Therefore, the calibration curves presented are only valid for the genres worked on or for materials with similar physical characteristics to the chips described in this study, even though it shows that the instantaneous moisture measurement equipment can be used to replace oven drying, provided it is previously calibrated.

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