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Research Article

By-products of the Sawmill Process in a Forest Company: Their Physical, Chemical and Energetic Evaluation for Pellets and Briquettes

Lucero A. REYES-RODRÍGUEZ[1], Luis J. AVIÑA-BERUMEN[1], Faustino RUIZ-AQUIÑO[2],
J. René RANGEL-MÉNDEZ[3], Rafael HERRERA-BUCIO[4], Gerardo J. ANDRADE-MARTÍNEZ[5],
Jose G. RUTIAGA-QUINONES*[4]

[1]Universidad Juárez del Estado de Durango, Durango, MEXICO
[2]Universidad de la Sierra Juárez, Ixtán de Juárez, Oaxaca, MEXICO
[3]Instituto Potosino de Investigación Científica y Tecnológica, A. C., San Luis Potosí, San Luis Potosí, Mexico
[4]Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán, MEXICO
[5]Compañía Forestal Vizcaya, Durango, Durango, MEXICO
*Corresponding Author: rutiaga@umich.mx

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Abstract

Aim of study: The physical characteristics and the chemical and energetic properties of bark and sawdust from a sawmill were determined, in order to identify their potential to be used for bioenergy purposes.

Area of study: The pine lignocellulosic residues were collected at the Forestal Viscaya company in Mexico.

Material and method: 50 kg of each biomass was collected as follows: bark samples were taken from the bark mill, and sawdust samples were taken from main saw, edger, trimmer, and the chipper machine. Moisture, granulometry, density, and chemical analyses were determined. The calorific value and tons of oil equivalent were also calculated.

Main results: The results indicate that the bark could be used to make briquettes, while the sawdust to make pellets. Particularly, the average calorific value varied from 16.55 to 23.78 MJ/kg for bark, while for sawdust the results varied from 19.49 to 21.04 MJ/kg. Using the most conservative model to estimate the calorific value, and taking into account the amount of bark and sawdust generated per year, it was determined that 2.265 equivalent tons of oil could be substituted.

Research highlights: The results show the potential of biomass for its possible energy use within the forestry company.

Keywords: Sawdust, Calorific value, Bioenergy, Ultimate analysis, *Pinus* spp.

Bir Orman İşletmesindeki Kereste Fabrikası Prosesinin Yan Ürünleri: Pelet ve Briketler için Fiziksel, Kimyasal ve Enerjisel Değerlendirilmesi

Öz

Çalışmanın amacı: Bir kereste fabrikasından çıkan ağaç kabuğu ve talaşın biyoenerji amaçlı kullanım potansiyelini belirlemek amacıyla fiziksel, kimyasal ve enerjik özellikleri belirlenmiştir.

Çalışma alanı: Çam lignoselülozik kalıntıları Meksika'da Forestal Viscaya şirketinden alınmıştır.

Materyal ve yöntem: Her bir biyokütleden 50 kg'lık kısım, kabuk değirmeninden kabuk örnekleri, ana testere, kenar kesme makinesi, kesici ve öğütücü makinesinden talaş örnekleri alınarak toplandı. Nem, granülometri, yoğunluk ve kimyasal analizler belirlendi. Ayrıca kalorifik değer ve ton petrol eşdeğeri de hesaplandı.

Temel sonuçlar: Sonuçlar, kabuğun briket yapımında, talaşın ise pelet yapımında kullanılabileceğini göstermektedir. Özellikle ağaç kabuğu için ortalama kalorifik değer 16.55 ile 23.78 MJ/kg arasında, talaş için ise 19.49 ile 21.04 MJ/kg arasında değişmektedir. Kalorifik değeri tahmin etmek için en ihtiyatlı model kullanılarak, yılda üretilen ağaç kabuğu ve talaş miktarı dikkate alınarak 2.265 eşdeğer ton petrolün ikame edilebileceği belirlenmiştir.

Araştırma vurguları: Sonuçlar, ormancılık şirketi bünyesinde biyokütlenin olası enerji kullanımı potansiyelini göstermektedir.

Anahtar Kelimeler: Talaş, Kalorifik değer, Biyoenerji, Nihai analiz, *Pinus* spp.

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Introduction

The current international energy crisis has made it necessary to seek new alternatives for energy generation, minimizing the sustained use of energy from fossil fuels, lest the environment continue to be compromised (Jekayinfa et al., 2020). It is also known that the use of fossil fuels has had harmful effects, both for the environment and for society, with high emissions of greenhouse gases and other polluting emissions (García et al., 2016; Specht et al., 2016). It is estimated that there is a demand, both for energy from renewable sources and from non-renewable sources (Hamza et al., 2021), but the generation of energy through renewable sources should promote new processes that use biomass combustion sources (da Luz & Moura, 2019; Jurasz et al., 2020; Sinsel et al., 2020), since biomass is considered an important source of energy (Tumuluru et al., 2010; Velázquez-Martí, 2018). There are numerous sources and types of biomass, which can provide marine, agricultural and forestry systems, and in general two large groups of most relevant sources can be identified: biomass derived from residues or remains of human activities and biomass from energy plantations (Velázquez-Martí, 2018).

In the forestry field, the wood industry has the characteristic of generating large volumes of lignocellulosic biomass during the process of extracting roundwood from the forest and processing it in the forestry industry, that is, this happens from the stage of supply, until obtaining the final product. These lignocellulosic by-products that are generated in the sawmilling process are usually not used or have limited use (Zavala-Zavala & Hernández-Cortés, 2000; SENER, 2012). The use of this waste in industrial and service processes, as well as in the residential environment, is a social need, whose objective would be to reduce the consumption of fossil fuels and the environmental impact they produce (Lesme-Jaén et al., 2006; García et al., 2016; Specht et al., 2016; Trubetskaya et al., 2019), and could be an economically competitive energy source with fossil fuels (García et al., 2012). In addition, it is known that the use of wood as energy is of little value and that it is important to focus efforts, both on wood waste and forest residues (Karinkanta et al., 2018).

On the other hand, with the obligation for the industry to use clean energy, specifically in Mexico, a favorable scenario would be expected in the medium term (2025 to 2030) with an increase in the demand for sawdust, chips, bark and other biomass residues (Arias-Chalico, 2018), so it is necessary to identify the characteristics and properties of lignocellulosic waste derived from the industrialization of wood, in order to find possible alternative uses. Given this circumstance, there has been interest in studying the possibility of implementing an energy cogeneration system in a forestry company located in the city of Durango, Mexico, using sawdust and bark, which are sawmill by-products. This forestry company mainly processes pine wood that comes from the region's forests. In the state of Durango, 20 species of pine have been registered, but the following are mainly used due to their commercial value: *Pinus ayacahuite* Ehrenb ex Schtld., *P. arizonica* Engelm., *P. cooperi* C. E. Blanco, *P. durangensis* Martínez, *P. engelmannii* Carriere and *P. teocote* Schide. ex Schltdl. & Cham. (García-Arévalo & González-Elizondo, 2003).

Since it is difficult to classify and separate the pine species in the forest, the forestry industry usually receives mixtures of pine species for industrialization. In the sawmilling process of the Vizcaya forestry company, residues of bark, slabs, cuttings, and sawdust are generated; chips are also produced. The coastal, offcuts and chips have a local market. Thus, the objective of this work was to carry out the physical, chemical and energetic evaluation of bark and sawdust residues generated during the sawmilling process, for its possible wood energy use within the same forestry company.

Material and Methods

Acquisition and Quantification of Timber By-products

The lignocellulosic residues of *Pinus* spp. were collected at the Forestal Viscaya company, located in the city of Durango, Durango, Mexico (24°03'39" North Latitude, 104°39'22" West Longitude, 1908 meters above sea level). To estimate the volume of by-products (bark and sawdust) generated during the sawmilling process, the methodology described by Reyes-Rodríguez (2015) was applied. Briefly, waste collection took place during an 8-hour shift. In each case, 50 kg of biomass was collected as follows: bark samples were taken from the bark mill, and sawdust samples were taken from main saw, edger, trimmer, and the chipper machine. Because the size of the material obtained from the edging was similar in size to sawdust (Table 1), in this work it will be considered as sawdust and not properly as shavings.

Physical Characteristics

The initial moisture content of the biomass was determined recently collected in the different machines of the sawmill process (UNE-EN ISO 18134-2, 2017). Subsequently, it was left to dry in the open air (approximately 10 %) to later determine the granulometry of the bark samples (UNE-CEN/TS 15149-1 EX, 2007) and sawdust samples (UNE-EN 15149-2, 2011). Both in bark and sawdust, the basic density (SCAN-CM 43:95, 1995) and the bulk density (Suzhou 2008; UNE-EN 15103, 2010) were determined. Samples of each lignocellulosic residue dried in the open air were ground in a Micron mill (Model K20F, series 236, Micron S.A. de C.V., Mexico City, Mexico) and sieved in a ROTAP equipment (Model RX-29, W.S. Tyler, Mentor, OH, USA) to obtain 40 mesh (425 micron) wood meal, used for the analyzes described below. Except for the ultimate analysis and the ash microanalysis, the other analyses were performed in triplicate and the mean value and standard deviation are reported.

Proximate Analysis

For this purpose, the amount of ash (UNE-EN 14775, 2010) and the content of volatile material (ASTM E 872-82, 1985) in each dry lignocellulosic residue were determined. Fixed carbon was calculated by difference.

Ultimate Analysis

The carbon, hydrogen and nitrogen content was carried out in a COSTECH brand elemental analyzer (Model 4010, Costech International S.p.A., Milan, Italy) following the UNE-CEN/TS 15104 EX (2008) standard. The oxygen content was calculated by difference.

Chemical Properties

The pH (Sandermann & Rothkamm, 1959) and ash content (UNE-EN 14775, 2010) were determined. Ash microanalysis was carried out on an Inductively Coupled Plasma-Optical Emission Spectrophotometer (ICP-AES) (VARIAN 730-ES, Varian Inc., (Agilent), Mulgrave, Australia) (Arcibar-Orozco et al., 2014). Solvent solubility was carried out by successive extraction in Soxhlet equipment (cyclohexane, acetone, methanol) and finally hot water under reflux, 6 hours in each case (Mejía-Díaz & Rutiaga-Quiñones, 2008). In the material after successive extraction, lignin (Runkel & Wilke, 1951) and holocellulose (Wise et al., 1946) were determined.

Energy Evaluation

Numerous investigations on mathematical models have been published for calculating the calorific value of various lignocellulosic materials. For our case, and based on the analyzes carried out here, the following prediction models were used: a) proximal analysis (Cordero et al., 2001), b) elemental analysis (Demirbaş, 1997), c) ash content (Sheng & Azevedo, 2005), and d) chemical composition (White, 1987). In addition, the electrical energy and the equivalent tons of oil were also estimated based on the biomass generated per year in the forestry company.

Results and Discussion

Quantification of Timber By-products

The results obtained indicated that the Forestal Vizcaya company, in an eight-hour shift, produces 64315 m^3 of sawn wood, and generates 30 m^3 of bark, 30.92 m^3 of sawdust, 8.14 m^3 of cuttings, and 45.0 m^3 of chips. The residue from cuttings and chips is sold by the company, so in this study only the residues of bark and sawdust were taken. The generated volume of residual biomass was 7830.0 m^3/year of bark and 8070.38 m^3/year of sawdust, or 2865.78 tons/year of bark and 2,431.53 tons/year of sawdust, with a total of 5297.39 tons/year of lignocellulosic by-products. In a study carried out in Ejido El Largo and Ejido El Balcón, in the state of

Durango, Mexico, on the quantification of residues in sawmilling processes, values were found that varied from 4500 to 7300 tons/year, respectively (SENER, 2012), and it was concluded that it is feasible to use them in electricity generation. The total value calculated here (5297 tons/year) is within those reported values, so it could be feasible to use these residues for cogeneration of electrical energy, given that the most efficient way to use biomass is cogeneration (SENER, 2012).

Physical Characteristics

Initial moisture content. The initial moisture content for the bark samples was 20.75% (±5.70), while for the sawdust samples the results were as follows: band saw 44.06% (±0.68), edger 38.23% (±2.23), trimmer 49.87% (±2.21) and chipper 35.35% (±1.92). These results are within the range reported for biomass (10 to 60 %) (Vassilev et al., 2010), or for recently cut lignocellulosic materials (50%) (Velázquez-Martí, 2018). However, the result of the initial moisture indicates that the values obtained are higher than the values suggested for the use of this biomass as densified biofuels. For example, to make pellets it is suggested that the moisture content of the material is not greater than 10 % (Obernberger & Thek, 2010) and to make briquettes the moisture content should not be greater than 18 % (ÖNORM 7135, 2000), because this high moisture content can affect the energy balance (Miranda et al., 2009). According to these results obtained, a drying process would be necessary to be able to use this biomass for the production of densified biofuels.

Bark granulometry. The bark particle size distribution was as following: sieve number and (percent retention): >63 (0.0%), 63 (0.0%), 45 (39.0%, ±0.28), 16 (30.0%, ± 0.15), 8 (23.5%, ±0.0) and ≤3.15 (7.5%, ±0.64). To use this biomass in the production of pellets, it would be necessary to reduce its particle size, since for this purpose the particle size must be less than 5 mm (Obernberger & Thek, 2010). However, briquettes could be made using the particle sizes of these studied materials, or mixtures of bark and sawdust, since there are experiences of making briquettes using lignocellulosic residues of different sizes (Morales-Máximo et al., 2020).

Sawdust granulometry. The particle size of the sawdust appears in Table 1 and it is observed that the sawdust generated in each sawmill machine corresponds in greater proportion to the size of 1.0 mm, followed by the size of 1.4 mm. It is known that the mechanical durability of the pellets depends on the particle size and that pellets made with particles of 0.5 to 1.0 mm have greater mechanical durability (Kaliyan & Vance, 2009). On the other hand, taking into consideration that the recommended particle size to make pellets should be less than 5 mm (Obernberger & Thek, 2010), it would not be necessary to reduce the size of the sawdust from this forestry company to use it for this purpose (Table 1). Bergström et al. (2008) used particle sizes of 1.0, 1.9, 4.0 and 8.0 mm (greater than 8.0 mm not used) of *Pinus sylvestris* sawdust to make pellets and concluded that grinding particle sizes below 8.0 mm is probably not necessary. With the lignocellulosic materials studied here, briquettes could be made, since there are experiences in making briquettes using sawdust and shavings of different sizes with good physical properties (Morales-Máximo et al., 2020), or making briquettes with mixtures of sawdust and shavings.

Table. 1. Granulometric distribution of sawdust (%)

Sieve (mm)	Main saw	Edger	Trimmer	Chipper
>3.15	2.42(±0.34)	0.28 (±0.16)	1.97 (±0.09)	0.11 (±0.15)
3.15	0.61 (±0.07)	0.82 (±0.07)	1.79 (±0.02)	0.71 (±0.18)
2.8	1.71 (±0.49)	8.52 (±0.73)	6.64 (±0.01)	8.53 (±1.40)
2.0	11.13 (±1.28)	23.50 (±1.43)	17.71 (±0.69)	25.11 (±3.61)
1.4	26.80 (±1.60)	23.59 (±0.28)	22.90 (±0.79)	25.46 (±0.51)
1.0	45.47 (±1.29)	26.09 (±0.34)	32.91 (±0.06)	30.81 (±2.88)
0.5	9.67 (±1.44)	12.04 (±1.36)	12.32 (±1.09)	7.52 (±2.47)
≤0.25	2.10 (±0.38)	4.78 (±0.66)	3.48 (±0.25)	1.48 (±0.46)

Basic density and bulk density. The basic density value for the bark was 363.2 kg/m^3 (Table 2), a value higher than the 333 kg/m^3

reported for *Pinus* sp. (Petráš et al., 2019). In the case of sawdust, the values found (Table 2) are less than 417 kg/m^3 obtained for *Pinus* sp. (Petráš et al., 2019). These differences in the results found could be explained by the pine species, in addition to the fact that it is known that there is an influence of growth conditions, and other factors, such as age and anatomical structure (Petráš et al., 2019).

The result of the bulk density for the bark (183.4 kg/m^3, Table 2) is close to the value of 180 kg/m^3 reported for coniferous bark (Francescato et al., 2008). The results obtained for sawdust varied from 99.8 to 170.8 kg/m^3; values of 143.0 Kg/m^3 (Stasiak et al., 2019) and 160 kg/m^3 (Francescato et al., 2008) have been reported for pine sawdust.

Table 2. Density of the bark and sawdust samples (kg/m^3)

Samples	Machine	Basic density	Bulk density
Bark	Debarker	363.2 (±0.00)	183.4 (±0.05)
Sawdust	Main saw	264.0 (±0.00)	170.8 (±0.00)
	Edger	172.2 (±0.00)	99.8 (±0.00)
	Trimmer	225.1 (±0.00)	123.6 (±0.03)
	Chipper	250.3 (±0.00)	161.1 (±0.00)

Proximate Analysis

The results of the proximate analysis are summarized in table 3. The values of volatile material (VM) varied from 77.28 % (sawdust) to 80.99 % (bark), while the fixed carbon (FC) content varied from 17.28 % (bark) to 21.78 % (sawdust). Data on volatile matter ranging from 69.5 to 86.3 % and for fixed carbon from 12.3 to 26.3 % have been reported for different woods (Vassilev et al., 2010) and the results obtained here fall within these ranges. The obtained values of volatile matter are relatively high, so this biomass has potential for energy use, since it is known that this volatile matter has a strong influence on the combustion process of biofuels (Olsson et al., 2003, 2004) and this volatile fraction is transformed into a gas and the fixed carbon is oxidized in the solid phase during the thermal decomposition process (Velázquez-Martí, 2018).

The amount of inorganic substances in the different samples varied from 0.36 to 1.73 % (Table 3). The bark contains a greater amount of mineral substances than sawdust, which agrees with previous reports (Fengel & Wegener, 1984; Martínez-Gómez et al., 2022). Based on the results obtained, class A2 pellets could be made with sawdust because this biomass meets the requirement of having an ash content of less than 1.5 % (Obernberger & Thek, 2010) and with the bark or with a mixture of bark and sawdust class B pellets could be produced because the ash content is less than 3.5 % (Obernberger & Thek, 2010). On the other hand, values less than 0.5 % of ash in biomass are desirable to make briquettes under international standards (ÖNORM, 2000).

Ultimate Analysis

Table 3 summarizes the result of the elemental analysis and the C/N ratio. The values found are within the range reported for biomass (Vassilev et al., 2010). Sulfur was not detected in the samples. In the wood the nitrogen and sulfur content is very low, but in other parts of the tree it is usually higher (Camps & Marcos, 2008). Knowing the elemental composition of biomass is essential for predicting the chemical reactions that will take place, for example, in combustion processes, and to determine the amount of reactants, products generated and the heat released in them; another application is the possibility of carrying out the balance of the different elements in their use (Velázquez-Martí, 2018). It is known that carbon and hydrogen are oxidized during combustion by exothermic reactions (formation of CO_2 and H_2O), and that the carbon and hydrogen content contribute positively to the higher calorific value, while the oxygen content negatively affects it. Hydrogen also influences the net calorific value due to the formation of water (Obernberger et al., 2006). During combustion, nitrogen is almost completely converted to nitrogen gas and nitric oxides (NOx) (Obernberger et al., 2006). The environmental impact of the combustion of solid fuels is constituted by NOx emissions (Nussbaumer, 2002) and this increases proportionally with the nitrogen content present in the biomass (Lyngfelt et al., 1996).

The C/N ratio is low compared to other reports for pine wood (Rutiaga-Quiñones, 2001; de Ramos e Paula et al., 2011). This relationship is important for the evaluation of the nutritional balance of the substrate of this biomass for the microorganisms that intervene in the fermentation process; high values indicate low nitrogen availability (Velázquez-Martí, 2018).

Table 3. Proximal analysis (%), elemental analysis (%) and C/N ratio of the biomass samples

Samples	Machine	VM	FC	Ash	C	H	N	O	C/N
Bark	Debarker	80.99 (±0.21)	17.28 (±0.37)	1.73 (±0.08)	56.73	2.50	0.39	38.65	145.5
Sawdust	Main saw	78.73 (±0.13)	20.82 (±0.29)	0.45 (±0.01)	56.29	4.33	0.46	38.47	122.4
	Edger	79.05 (±0.19)	20.59 (±0.12)	0.36 (±0.03)	54.33	4.95	0.41	39.95	132.5
	Trimmer	79.63 (±0.15)	19.98 (±0.41)	0.39 (±0.07)	54.20	5.20	0.50	39.71	108.4
	Chipper	77.28 (±0.11)	21.78 (±0.17)	0.94 (±0.06)	55.98	5.33	0.53	37.22	105.6

Chemical Properties

pH value. The result of the pH measurement of the lignocellulosic materials, collected in each sawmill machine, was the following: 3.70 (±0.02) (debarker), 4.75 (±0.01) (main saw), 4.74 (±0.01) (edger), 4.73 (±0.00) (trimmer) and 3.93 (±0.08) (chipper); it was observed that the bark is more acid than the sawdust, which coincides with the literature (Kollmann, 1959; Fengel & Wegener, 1984). The pH of the sawdust is practically the same in the three samples (average 4.7). The values found place these materials with a slightly acidic pH (Kollmann, 1959) and generally coincide with previous reports for different pine woods (Bernabé-Santiago et al., 2013).

Microanalysis of the ash. In general, thirteen chemical elements were detected in the ashes (Table 4). The highest concentration corresponds to calcium, followed by potassium and magnesium, which coincides with data reported for wood and bark (Martínez-Pérez et al., 2015; Rutiaga-Quiñones et al., 2020; Martínez-Gómez et al., 2022).

Silicon, calcium, magnesium, potassium and sodium are considered important for combustion, being chemical elements of the ash, and in this case the concentration of calcium and sodium is below the limit of the concentration range of relevant elements for combustion in ash of solid biofuels (Obernberger et al., 2006), while the concentration of magnesium is slightly above this range, and potassium in two samples exceeds this range. On the other hand, the concentration of calcium, potassium and zinc in our biomass samples are below the guide values and guide ranges for elements in solid ash in biofuels for trouble-free combustion (Obernberger et al., 2006). It is known that high concentrations of calcium increase the melting point of the ash and minimize the amount of it in combustion equipment (Obernberger & Thek, 2010). When potassium is found in high amounts, it lowers the melting point of the ash, producing slag and deposits in combustion equipment, it can also increase the amount of aerosols during combustion, dirtying the boilers and generating the emission of fine particles (Obernberger & Thek, 2004; Van Lith et al., 2006). High concentrations of magnesium can increase the melting point of the ash (Obernberger & Thek, 2010). When sodium is present in high concentrations, it reduces the melting point of the ashes (Obernberger & Thek, 2010) and favors the formation of deposits when the vapors condense inside the combustion equipment (Werkelin et al., 2011). In relation to zinc, it is likely that it plays an important role in the formation of aerosols during combustion (Van Lith et al., 2006). From the results obtained, it would be expected that when using this biomass as a solid biofuel, the problems associated with the inorganic composition in the combustion process are minimal.

Table 4. Amount of chemical elements present in bark ash and sawdust ash (wt.%).

E	Bark	Sawdust			
	D	Ms	Ed	T	Ch
Al	1.14	0.37	0.47	0.38	1.50
B	0.13	0.28	ND	ND	0.24
Ba	0.08	ND	0.22	0.15	0.09
Ca	8.37	13.57	9.07	6.71	7.22
Cu	0.01	ND	0.01	0.01	0.02
Fe	0.60	0.48	0.36	0.30	0.93
K	2.53	7.31	6.06	4.87	2.58
Mg	1.24	2.61	2.42	1.89	1.19
Mn	0.33	1.07	1.24	1.01	0.42
Na	0.06	0.20	0.16	0.10	0.07
P	0.55	1.35	1.52	1.22	0.78
Sr	0.05	ND	0.08	0.06	0.05
Zn	0.05	ND	0.10	0.08	0.05

E: elements, D; debarker, Ms: main saw, Ed: edger, T: trimmer, Ch: Chipper, ND: not detected

Extractives. Table 5 summarizes the results of the successive extraction applied. The bark contains a higher amount of extractives than the sawdust samples, which is consistent with the literature (Kollmann, 1959; Fengel & Wegener, 1984). The biomass generated in the chipper contains a greater amount of extractives compared to the sawdust samples, which could be explained by the presence of bark in said biomass (Table 5). In the bark, the highest solubility was in acetone followed by hot water, while in the sawdust samples the highest solubility was in cyclohexane followed by acetone. In the case of sawdust, the results found are higher compared to data reported for pine wood (Bernabé-Santiago et al., 2013).

Lignin and holocellulose. The values found for the cell wall components appear in Table 5 and it is observed that the bark contains a higher concentration of lignin than sawdust, which coincides with the literature (Fengel and Wegener, 1984). In general, the result for sawdust coincides with previous data for pine wood (Bernabé-Santiago et al., 2013; Martínez-Gómez et al., 2022). In relation to holocellulose, the bark presents low concentration and its value is lower compared to values reported for coniferous woods (Martínez-Gómez et al., 2022). In the case of holocellulose in sawdust, the values found are close to the data for pine wood (Bernabé-Santiago et al., 2013; Martínez-Gómez et al., 2022) and are generally within the range reported in the literature for softwoods (Fengel & Wegener, 1984; Rowell, 2005).

Table 5. Extractives, lignin and holocellulose in the samples (%)

Samples	Machine	Solvent				Total (%)	Runkel lignin (%)	Holocellulose (%)
		Cyclohexane	Acetone	Methanol	Hot water			
Bark	Debarker	5.61 (±0.15)	10.90 (±0.35)	6.68 (±0.47)	1.05 (±0.27)	24.24	29.32 (±0.47)	46.59 (±1.81)
Sawdust	Main saw	6.24 (±0.56)	4.48 (±0.01)	0.49 (±0.02)	2.33 (±0.43)	13.54	26.89 (±0.33)	60.10 (±0.12)
	Edger	5.32 (±0.06)	2.69 (±0.03)	0.90 (±0.03)	1.91 (±0.09)	10.82	26.09 (±0.54)	63.16 (±0.01)
	Trimmer	2.89 (±0.47)	2.60 (±0.59)	0.88 (±0.03)	2.07 (±0.02)	8.44	23.00 (±0.03)	68.74 (±0.17)
	Chipper	10.94 (±0.24)	10.26 (±0.32)	0.57 (±0.13)	0.38 (±0.22)	22.15	24.79 (±0.04)	53.40 (±0.83)

Energy Evaluation

The values calculated for the calorific value using different mathematical models are shown in Table 6. In the case of sawdust, which was collected in the different sawmill machines, an average value is reported, since it would be assumed that the forestry company would use the sawdust all together as biofuel material. The calorific value results calculated based on the models for proximal analysis and for elemental analysis (Table 6) are close to the values reported for pine wood obtained by the same method (Cordero et al., 2001; Demirbaş, 1997).

The average calorific value calculated for the bark ranged from 16.55 MJ/kg (ash content model) to 23.78 MJ/kg (chemical composition model), as shown in Table 6. The typical value for bark is 19.2 MJ/kg (Francescato et al., 2008). For sawdust, the value of the calculated average calorific value varied from 19.49 MJ/kg (ultimate analysis model) to 21.04 MJ/kg (chemical composition model). The typical range for softwoods is from 18.8 MJ/kg to 19.8 MJ/kg. These differences could be explained by the method used. In summary, the average values of calorific value calculated for bark and for sawdust with the indicated mathematical models had the following behavior: ultimate analysis < ash content < proximal analysis < chemical composition (Table 6).

On the other hand, based on the fact that the sawmill produces 2,865.78 tons/year of bark and 2,431.53 tons/year of sawdust, from the value of the calorific value calculated with each mathematical model used, kW h/kg, MW h/year and tons of oil equivalent (Toe) have been calculated (Table 6). The results obtained for kW h/kg (Table 6) are close to the reported range (5.1 to 5.4 kW h/kg) for softwoods (Suzhou, 2008). With the model for calculating the most conservative calorific value (ultimate analysis), there would be 2,265 tons of oil equivalent (Table 6), which is equivalent to 16,602 barrels of oil. These results calculated here, and with other future studies on the technical and economic feasibility, could help the forestry company to design strategies and set energy efficiency objectives, and assess the feasibility of incorporating the amount of lignocellulosic biomass that is generated annually in its sawmill process, cogeneration of energy and reduce dependence on fossil fuels.

Table 6. Higher calorific value, electrical energy and equivalent tons of oil

Mathematical model	Samples	Machine	HHV (MJ/kg)	Average	kW h/kg	MW h/year	Eto
Proximate analysis (Cordero et al. 2001)	Bark	Debarker	19.96	19.96	5.548	15890	1367
	Sawdust	Main saw	20.82	20.81	5.781	14057	1209
		Edger	20.80				
		Trimmer	20.68				
		Chipper	20.92				
				Summe	11.329	29947	2576
Ultimate analysis (Demirbas 1997)	Bark	Debarker	16.55	16.55	4.598	13176	1133
	Sawdust	Main saw	19.03	19.49	5.414	13165	1132
		Edger	19.03				
		Trimmer	19.37				
		Chipper	20.53				
				Summe	10.012	26341	2265
Ash content (Sheng and Azevedo 2005)	Bark	Debarker	19.51	19.51	5.420	15532	1336
	Sawdust	Main saw	19.81	19.79	5.498	13368	1149
		Edger	19.83				
		Trimmer	19.82				
		Chipper	19.70				
				Summe	10.918	28900	2485
Chemical composition (White 1987)	Bark	Debarker	23.78	23.78	6.606	18932	1628
	Sawdust	Main saw	20.74	21.04	5.845	14212	1222
		Edger	20.46				
		Trimmer	20.17				
		Chipper	22.80				
				Summe	12.451	33144	2850

Conclusions

The physical characteristics and the chemical and energetic properties of bark and sawdust from a sawmill were determined, in order to identify their potential to be used for bioenergy purposes within the forestry company. Annually 2865.78 tons of bark and 2431.53 tons of sawdust are generated in the sawmill. The initial moisture content of both materials is relatively high, so it would be necessary to dry them before using them as biofuel. Due to the particle size, the bark could be used, alone or with sawdust, in the preparation of briquettes. Due to the particle size and ash content, the sawdust could be used to produce class A2 pellets. The major chemical elements in both materials were calcium and potassium. The calculated calorific value varied from 16.55 MJ/kg to 23.78 MJ/kg for bark, while for sawdust the results varied from 19.49 MJ/kg to 21.04 MJ/kg. Finally, the results obtained show the potential of biomass for its possible energy use within the company and the calculations made suggest that 2,265 equivalent tons of oil per year could be substituted.

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N/A

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Author Contributions

Conceptualization: L.A.R.R., J.G.R.Q. and L.J.A.B.; Investigation: L.A.R.R.; Material and Methodology: L.A.R.R., G.J.A.M. and J.R.R.M.; Supervision: J.G.R.Q., L.J.A.B. and R.H.B.; Visualization: R.H.B. and F.R.A.; Writing-Original Draft: L.A.R.R. and J.G.R.Q.; Writing-review & Editing: L.A.R.R., F.R.A. and J.G.R.Q. All authors have read and agreed to the published version of manuscript.

Conflict of Interest

The author has no conflicts of interest to declare.

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