Wood Chemical Composition of Five Tree Species from Oaxaca, Mexico

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The wood chemical composition was determined for five tree species that cohabitate in the forest of Ixtlán de Juárez (Oaxaca, Mexico). These species were *Alnus acuminata*, *Arbutus xalapensis*, *Myrsine juergensenii*, *Persea longipes*, and *Prunus serotina*. The chemical composition was then correlated with the higher heating value of the wood. The chemical components determined were total extractives, ash, lignin, and holocellulose (alpha cellulose and hemicelluloses). The extractives were separated using Soxhlet equipment, and the ash obtained was analyzed *via* atomic absorption spectrometry. On average, the species presented 8.26 to 19.64% of total extractives, 0.56 to 1.50% of ash, 23.1 to 37.2% of lignin, 74.0 to 79.5% of holocellulose, 56.3 to 66.3% of α-cellulose, and 12.3 to 21.0% of hemicelluloses. In the ash, higher percentages of calcium, potassium, and magnesium were detected. The amount of chemical components was different between species ($p \leq 0.05$). The higher heating value showed a positive correlation with the extractives content ($r = 0.582$), while with the ash content it was negative (-0.575). The high proportions of polysaccharides predict good performance of these species in pulp production, and the calorific value indicates that they have the potential for use as fuel.

Keywords: Extractives; Lignin; Sapwood; Heartwood

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INTRODUCTION

Wood contributes to the chemical, pulp and paper, cosmetics, and pharmaceutical industries. The chemical composition of wood, in terms of identifiable elements or molecules, involves the isolation, purification, and characterization of chemical components. A knowledge of the chemical composition of timber species is necessary in the search for alternatives to forest exploitation. The main components of wood are cellulose, hemicelluloses, and lignin, together with low percentages of extractives and inorganic substances (Fengel and Wegener 2003; Walker 2010). However, the chemical composition of wood cannot be precisely defined for a group of species or even for a given species, because it varies according to the part of the tree, type of wood, geographic location, and growth conditions (Hillis 1971; Hon and Shiraishi 2001). Furthermore, it depends on the tree's anatomical structure, due to the different substances that conform it (Honorato-Salazar 2002).

Studies on the chemical composition of wood mostly include parameters such as pH, lignin content, α-cellulose, hemicelluloses, total extractives, and ash. Bautista and Honorato (2005) studied the wood of four *Quercus* species. Bárcenas-Pazos *et al*. (2008) focused on the chemical composition of two shrub species of white oak; Téllez-Sánchez *et al*. (2010) researched the heartwood components of *Andira inermes* (W. Wright); and Honorato-Salazar *et al.* (2015) examined the main chemical components of the wood of *Ceiba pentandra*, *Hevea brasiliensis*, and *Ochroma pyramidale*. Recently, Herrera-Fernández *et al*. (2017) reported on the chemical composition of wood and bark of three oak species.

Studies of the chemical composition of tree species from the Sierra Juárez in the state of Oaxaca (Mexico) are scarce. Therefore, it is important to expand knowledge of the chemical constituents of this wood so that the region's timber resources will have greater potential and utility in technological and industrial processes such as the production of pulp and paper, tannins, and as natural wood preservatives (Honorato-Salazar and Hernández-Pérez 1998; Bautista and Honorato 2005; Bernabé-Santiago *et al*. 2013). The purpose of this work is to determine the basic chemical composition in percentages of total extractives, ash, lignin, α-cellulose, and hemicelluloses in heartwood and sapwood, and correlate them with the higher heating value of the wood of five broadleaved species in the forests of the community of Ixtlán de Juárez, Oaxaca, México.

EXPERIMENTAL

Materials

Study area

The study was conducted in the forest community of Ixtlán de Juárez, in the Northern mountain range of Oaxaca (17°18'16" and 17°30'00" N, 96°31'38" and 96°22'00" W) (Castellanos-Bolaños *et al.* 2008). The annual average temperature is 20 °C and rainfall ranges between 800 and 1200 mm per year (Aquino-Vásquez *et al*. 2012). Four types of climate prevail: sub-humid temperate, sub-humid temperate with summer rains, humid temperate with summer rains, and humid warm weather with rains all year round (STF 2015).

Tree selection and sample preparation

The material for analysis was gathered from healthy trees representative of the study area. Two trees were collected for each species: *Alnus acuminata* subsp. *arguta* (Schltdl.) Furlow, *Arbutus xalapensis* Kunth, *Myrsine juergensenii* (Mez) Ricketson & Pipoly, *Persea longipes* (Schltdl.) Meissner, and *Prunus serotina* Ehrh. From each tree, a 2.5-meter-long log was taken, from which slices of *ca*. 2 cm were cut. In each slice, the sapwood was separated from the heartwood, the samples were dried outdoors under shade, and then ground in a Wiley-type mill (Thomas Scientific, Logan, NJ, USA) to obtain a particle size of 60-mesh (0.250 mm). This wood sample was used for the different chemical analyses, which were performed in triplicate.

Methods

Chemical characterization of the wood and higher heating value

Total extractives content of the wood samples was attained following the ASTM D1105-96 (2007) standard, using Soxhlet extraction equipment. The solvents used were a mixture of ethanol-toluene 2:1 v/v, ethanol, and finally hot water. Klason lignin was determined based on the ASTM D1106-96 (2007) standard, by hydrolysis with 72% and 3% sulfuric acid (H_2SO_4). The holocellulose content was obtained using the acidified sodium chlorite technique (Fengel and Wegener 2003). From the holocellulose, the α-cellulose content was determined according to the method ASTM D1103-60 (2007) with a 17.5% sodium hydroxide (NaOH) solution. Hemicellulose content was calculated from the differences between the contents of holocellulose and α-cellulose (Camarena-Tello *et al*. 2015). For ash content, the ASTM D1102-84R07 (2007) method was followed. Finally, qualitative analysis of the ash content was conducted in a Perkin Elmer Analyst 200 atomic absorption spectrometer (PerkinElmer, Inc., Shelton, CT, USA).

The higher heating value (HHV) of the wood was determined in 1.5 cm^3 sapwood and heartwood samples, using a 1341 plain jacket calorimeter (Parr Instrument Company, Moline, IL, USA).

Statistical analysis

To determine differences between species and the type of wood (sapwood and heartwood) in each of the chemical components, an analysis of variance was performed with the GLM procedure of the statistical package SAS® Version 9.0 (SAS Institute Inc., Cary, NC, USA). A factorial design was used, where the factors were the species and the type of wood. When it was determined that the variation factor produced a significant effect on the parameter of interest, the minimum square means were compared using the Tukey test ($\alpha = 0.05$) for multiple comparisons. The relationship between the chemical composition and the higher calorific value was determined using the Pearson correlation coefficient (r). Linear regression equations were generated by the STEPWISE variable selection process to estimate the HHV as a function of the chemical components. The normality assumption in the distributed residuals was verified with the Shapiro-Wilk test (Shapiro and Wilk 1965).

RESULTS AND DISCUSSION

Extractives

The analysis of variance indicated that there were differences between species ($p < 0.05$), with higher contents in the wood of *A. xalapensis* (19.42%) and *P. serotina* (19.64%) (Table 1). By wood type, the results indicate statistical equality within each species (Table 2). However, a higher percentage of extractives in heartwood was determined with respect to sapwood in *A. xalapensis* and *P. serotina*. This condition, where the extractives are present in a lower amount in sapwood, is generally found in other woods, although this is not always the case (Rutiaga-Quiñones *et al*. 2010). The percentage of total extractives for most tree species is less than 10% but can reach up to 30% in some species (Forest Products Laboratory 2010).

The percentage of extractives for *P. serotina* was higher than *Prunus hintonii* (Ávila-Calderón and Rutiaga-Quiñones 2015). The high extractives content values indicate high natural durability of the wood (Fengel and Wegener 2003; Araujo and Paes 2018). The differences registered are attributed to the solvents used (Honorato-Salazar *et al*. 2015), as well as the extraction methods. In addition, it is important to consider that the amount and composition of extractives also depends on the species, part of the tree from which they were collected, time of year, and growth conditions, among other factors.

Table 1. Average Values of the Chemical Composition of Wood of Five Species

Species	TE (%)	AC (%)	Lignin	Holocellulose	α-cellulose	Hemicelluloses
A. acuminata	10.35 (1.41)b	0.62 (0.05)c	31.74 (6.33)a,b	77.24 (2.04)b, c	56.28 (2.51)d	20.96 (4.11)a
A. xalapensis	19.42 (2.71)a	0.56 (0.10)c	23.09 (9.23)c	75.45 (1.17)c,d	60.19 (1.39)b,c	15.26 (2.20)b
M. juergensenii	10.53 (1.24)b	0.79 (0.10)b	23.11 (5.50)c	79.54 (1.42)a	66.31 (1.16)a	13.23 (2.39)b
P. longipes	8.26 (3.15)b	1.50 (0.19)a	28.88 (4.18)b,c	74.05 (1.67)d	61.74 (2.00)b	12.31 (3.35)b
P. serotina	19.64 (2.55)a	0.68 (0.11)b,c	37.20 (6.43)a	78.49 (1.28) b, a	59.11 (2.27)c	19.38 (1.97)a

TE = Total extractives; AC = ash content;
Values with different lowercase letters in columns are statistically different ($p \leq 0.05$)

Table 2. Chemical Composition of Wood of Five Tree Species (%)

Species		TE	AC	Lignin	Holocellulose	α-celluloses	Hemicelluloses
A. acuminata	SW	10.65 (0.76)a	0.63 (0.04)a	32.16 (6.71)a	75.63 (0.73)a	58.10 (2.24)a	17.54 (1.91)a
	HW	10.05 (1.89)a	0.62 (0.06)a	31.33 (6.54)a	78.84 (1.56)a	54.47 (0.97)a	24.38 (2.32)b
A. xalapensis	SW	17.69 (0.89)a	0.62 (0.09)a	25.93 (8.46)a	75.46 (1.26)a	60.99 (1.18)a	14.47 (2.31)a
	HW	21.15 (2.86)a	0.50 (0.08)a	20.25 (9.82)a	75.45 (1.20)a	59.39 (1.16)a	16.05 (1.95)a
M. juergensenii	SW	10.58 (1.37)a	0.87 (0.06)a	21.83 (5.65)a	79.07 (1.47)a	66.60 (1.39)a	12.47 (2.68)a
	HW	10.48 (1.23)a	0.72 (0.07)a	24.39 (5.54)a	80.02 (1.32)a	66.03 (0.89)a	13.99 (1.99)a
P. longipes	SW	7.74 (3.58)a	1.56 (0.24)a	27.98 (3.47)a	74.24 (2.23)a	62.49 (2.68)a	11.75 (4.67)a
	HW	8.77 (2.91)a	1.44 (0.15)a	29.78 (4.94)a	73.86 (1.06)a	60.98 (0.53)a	12.88 (1.48)a
P. serotina	SW	18.30 (1.51)a	0.73 (0.14)a	36.57 (6.89)a	78.09 (1.42)a	58.27 (2.31)a	19.82 (2.35)a
	HW	20.98 (2.77)a	0.63 (0.05)a	37.83 (6.52)a	78.88 (1.11)a	59.95 (2.08)a	18.94 (1.59)a

SW = sapwood; HW = heartwood; TE = Total extractives; AC = ash content;
For each species, equal letters in the direction of the columns indicate statistical equality by type of wood ($p \geq 0.05$)

Lignin

The five tree species in the present study did not present significant statistical differences between sapwood and heartwood for this chemical component (Table 2). However, comparison of the amount of lignin between species indicated statistical differences, with average values ranging from 23.1% for *A. xalapensis* to 37.2% for *P. serotina* (Table 1). The lignin content of *A. xalapensis* was found within the range reported by different authors for species of the genus *Arbutus*: *A. andrache* 24% (Rowell 1984) and *A. menziesii* 26.3% (Olsson and Salmén 1997). Furthermore, the amount of lignin in the wood of *A. acuminata* (31.7%) was similar to the value that Moya-Roque and Tenorio-Monge (2013) mention for the same species (33.0%). For *P. longipes* wood, lignin values were higher than those obtained for *Persea americana* (19.4%) (Anzaldo-Hernández *et al*. 2004) and for *Persea borbonia* (23.6%) (Rowell 1984).

The above differences can be associated with the age of the individuals, because the wood of young trees exhibits lower lignin content than the wood of mature trees (Zaki *et al*. 2012). Low quantities of lignin in lignocellulosic materials are desirable in the paper industry because they increase the pulp yield (Rowell *et al*. 2005; MacLeod 2007). In contrast, if the wood is intended for energy production, species with higher lignin contents are required because of the positive effect this has on the wood's calorific value (Rivera and Uceda 1987).

Holocellulose

Holocellulose (alpha cellulose and hemicelluloses) represents the total fraction of polysaccharides in wood. High proportions of polysaccharides increase the yield of paper pulp (MacLoed 2007). The average holocellulose interval in this study was 74.0 to 79.5%, which coincides with that published for other hardwoods (71.0 to 89.1%) by Tsoumis (1991). Additionally, the value (80.2%) was similar to the average for species of the genus *Eucalyptus* (Orea-Igarza *et al*. 2006), and is at the upper limit reported by Fengel and Wegener (2003) for hardwoods in temperate zones of different countries (49.2 to 89.2%). For *P. longipes* wood, the holocellulose value was similar to the 73.4% reported for *P. americana* by Anzaldo-Hernández *et al*. (2004). For wood type there were no significant statistical differences between sapwood and heartwood (Table 2). The species in the present study could be used in pulping processes due to their polysaccharide content. On the basis of polysaccharides content, the species in the present study are considered suitable for obtaining cellulose pulp (Herrera-Fernández *et al*. 2017).

Alpha Cellulose

Alpha cellulose represents the non-degraded cellulose fraction of high molecular weight (Pintor-Ibarra *et al*. 2018). Several authors have found differences in the alpha cellulose content of sapwood and heartwood in broadleaved species, reporting lower contents in heartwood than in the albura (Mariani *et al*. 2005; Gao *et al*. 2011). In the present study, no statistical differences were found between sapwood and heartwood (Table 2). Statistical analysis between species revealed higher alpha cellulose content for *M. juergensenii* and a lower amount in *A. acuminata*. It was found that between *A. xalapensis* and *P. longipes* there were no significant differences ($p = 0.0556$), nor between *A. xalapensis* and *P. serotina* ($p = 0.1768$). For *P. longipes* the content of α-cellulose was higher than that reported for *P. americana* (39.4%) (Anzaldo-Hernández *et al*. 2004); and for *A. acuminata* it was higher than that reported by Moya-Roque and Tenorio-Monge (2013) for the same species (43.2%). This component is determined by the geographical location and the growth conditions of the tree (Honorato-Salazar and Hernández-Pérez 1998). The amount of α-cellulose in the wood of the species studied was high, with higher values when compared with the works of other authors. It is possible that the difference in cellulose yields was due to the use of different analytical methods (Bautista and Honorato 2005).

Hemicellulose

Hemicellulose content exhibited statistical differences in sapwood (17.5%) and heartwood (24.4%) of *A. acuminata*. The average range of hemicellulose content was 12.3 to 21.0%, where *A. acuminata* wood presented the highest hemicellulose content and the *P. longipes* wood presented the lowest. These values were in accordance with the 10 to 20% range mentioned by Fengel and Wegener (2003). In hardwood, hemicelluloses contain mostly xylan (Rowell *et al*. 2005). The hemicellulose content registered in the wood of the species studied was low when compared with the 18.4 to 21.6% ranges reported for five oak species (Honorato-Salazar and Hernández-Pérez 1998), but was found within the published values (12.6 to 27.1%) for hardwoods in temperate zones of different countries (Fengel and Wegener 2003). The amount, structure, and composition of the hemicelluloses varies between genus, species, cell type, and location in the cell wall (Walker 2010). Hemicelluloses greatly influence the properties of fibers in paper making because they favor the tensile strength properties of the sheets by increasing the bonding capacity of the fiber surface (Libby 1980).

Ash

The ash content in sapwood ranged from 0.63 to 1.56% for *A. acuminata* and *P. longipes*, respectively, and in heartwood from 0.50% for *A. xalapensis* to 1.44% for *P. longipes* (Table 2). The amount of ash exhibited a structure-based tendency, where the highest percentages were found in sapwood, which was in agreement with Kollmann (1959), who mentioned that sapwood is usually richer in ash than in heartwood. The values of the present study are similar to the ranges reported for sapwood (0.25 to 3.54%) and heartwood (0.22 to 2.10%) of ten hardwoods in the state of Michoacán, Mexico (Martínez-Pérez *et al.* 2015).

The percentage of ash generated from *A. xalapensis* wood was less than the 0.8% of *Arbutus andrache* that Rowell (1984) mentioned, while the ash content for *P. serotina* wood was similar to the 0.60% reported for *Prunus hintonii* (Ávila-Calderón and Rutiaga-Quiñones 2015). Moya-Roque and Tenorio-Monge (2013) reported a lower ash content (0.38%) than the one found in this study for the same *A. acuminata* species. The difference in the ash content determined in this study is reasonable because according to Kollmann (1959), the amount of ash varies with the species and within the same species, according to season and weather conditions. Furthermore, these variables also influence quantity and composition of ash.

Ash content is an important parameter to consider for the choice of a biomass fuel. Under this criterion *A. xalapensis* wood could be considered as the best quality. However, a high ash content causes problems because its accumulation obstructs the flow of combustion gases inside biomass boilers (Werkelin *et al*. 2011), as well as causing corrosion, erosion, and abrasion, for which special considerations must be taken for the handling of ash if biomass of *P. longipes* is chosen for fuel.

Residuals analysis confirmed the hypothesis of normality in all chemical composition values. The Shapiro-Wilk test showed that the probability value (P) associated with the values of the Shapiro-Wilk statistic (W) were greater than the significance level $\alpha = 0.05$ (Table 3), so that the null hypothesis (H_0) is not dismissed. Hence, it is verified that all the data come from a normally distributed population. so that is not dismissed H0

Table 3. Statistical and Probability Values of the Shapiro-Wilk Test for Verifying the Normality of Residuals

Parameter	Statistic (W)	P value (*Pr* < W)
Total extractives	0.984	0.637
Ash content	0.982	0.528
Lignin	0.981	0.492
Holocellulose	0.990	0.927
Hemicelluloses	0.982	0.534
HHV	0.968	0.125
Pr = probability		

Chemical Composition of Ash

The qualitative analysis of wood ash by atomic absorption spectrometry is shown in Table 4. The highest proportions of inorganic elements found in the five species were calcium (37.9 to 48.4%) and potassium (21.6 to 26.0%), followed by magnesium (9.2 to 12.9%). These are the main elements in the inorganic substances of wood and amounted to as much as 80% in ash. Furthermore, these chemical elements have been found in other broadleaved trees (Fengel and Wegener 2003). The remaining elements were found in a range of 0.19 to 7.14%, where aluminum and zinc were the least abundant in all species.

The majority of the inorganic substances detected in the ash of these species in general were in agreement with data reported in the literature. Elements, such as calcium, potassium, magnesium, manganese, and sodium, among others, were detected in hardwoods and conifers (Martínez-Pérez *et al*. 2015). For two species of the genus *Quercus*, Ruiz-Aquino *et al.* (2015) found that the most abundant minerals were calcium, potassium, magnesium, and sodium. Similarly, for *Prunus hintonni* the elements mainly present were calcium (55.6%), potassium (26.7%), and magnesium (14.7%) (Ávila-Calderón and Rutiaga-Quiñones 2015), which coincides with the values found for *P. serotina* in this analysis. Likewise, similar values were found for the main chemical elements in *Persea* sp. and *A. xalapensis* (Martínez-Pérez *et al.* 2015).

Table 4. Inorganic Elements Detected in Wood Ash (%)

Inorganic Elements	*A. acuminata*	*A. xalapensis*	*M. juergensenii*	*P. longipes*	*P. serotina*
Calcium	37.88	48.44	40.18	37.94	42.75
Potassium	24.73	21.56	22.51	26.04	24.74
Magnesium	12.94	9.23	11.06	12.43	9.76
Sodium	11.77	10.13	12.88	10.81	10.00
Manganese	5.99	4.61	6.23	7.14	6.49
Iron	2.62	2.94	3.92	3.18	2.46
Copper	2.46	1.39	2.11	1.62	1.74
Zinc	0.93	0.79	0.90	0.67	1.04
Aluminum	0.68	0.91	0.21	0.19	1.01

Inorganic substances are nutritious elements and have an important function in the growth of trees (Fengel and Wegener 2003). Hence, the chemical elements examined in these samples are basically those that are common in vascular plants (Martínez-Pérez *et al.*

2015). The difference in ash composition depends on the kind of species, part of the tree, geographical location, and the environmental conditions under which the tree has grown (Siddique 2012).

Higher Heating Value

Significant statistical differences were determined between sapwood and heartwood of *P. serotina*, with higher percentages in heartwood (Table 5). These values can be attributed to the extractives content in *P. serotina* heartwood (20.98%). According to Kollman (1959), a higher percentage of extractives increases the calorific value in wood.

The species with the lowest calorific value were *P. longipes* and *M. juergensenii* (Table 5). The values obtained in this study were within the reported range for 20 tree species of Peru (19.3 to 20.5 MJ kg^{-1}) (Rivera and Uceda 1987), and were higher than the average registered for 10 Mexican species for sapwood (17.8 MJ kg^{-1}) and heartwood (18.6 MJ kg^{-1}) (Martínez-Pérez *et al*. 2015). Although these HHV values were similar to those reported by different studies (19.8 MJ kg^{-1} by Uceda (1984) and 19.4 MJ kg^{-1} by Ruiz-Aquino *et al*. (2015)), by themselves they should not be considered as the main indicator of the benefits of a fuel (Corradi-Pereira *et al*. 2012), because volatile matters and ash have a highly significant influence on fuel quality (Rivera and Uceda 1987).

Table 5. Higher Heating Value of Wood of Five Tree Species

HHV	*A. acuminata*	*A. xalapensis*	*M. juergensenii*	*P. longipes*	*P. serotina*
Sapwood	20.15 (0.20) a	20.07 (0.17) a	19.44 (0.14) a	19.70 (0.30) a	19.93 (0.23) a
Heartwood	20.17 (0.07) a	20.19 (0.19) a	19.56 (0.06) a	19.56 (0.14) a	20.46 (0.10) b
Average	20.16 (0.14) A	20.13 (0.19) A	19.50 (0.12) B	19.63 (0.24) B	20.20 (0.32) A

Equal lowercase letters in the direction of the columns indicate statistical equality by type of wood ($p \geq 0.05$); Equal uppercase letters in the direction of the rows indicate statistical equality by species ($p \geq 0.05$)

Correlation Between Calorific Value and Chemical Components

As shown in Table 6, high HHV correlated positively with total extractives content (r = 0.582), *i.e.*, as the extractives increased, the HHV increased. According to Moya and Tenorio (2013), HHV is influenced by the chemical composition of wood, mainly by lignin and extractives.

Likewise, positive correlations were observed between HHV and lignin, and HHV and hemicelluloses. It has been shown that woods that contain high amounts of lignin have better fuel quality (Rivera and Uceda 1987). Lignin is present mainly in the cell wall, it is one of the most abundant polymers in nature after cellulose and hemicelluloses,| and it has a higher HHV than the fraction of hemicelluloses (López *et al*. 2011).

In contrast, HHV exhibited a tendency to decrease with higher ash values (r = -0.575). This behavior was also reported by Ngangyo-Heya *et al*. (2016) for five semi-arid Mexican species and by Martínez-Pérez *et al.* (2012) who reported that HHV tends to decrease as content of mineral substances increases.

Table 6. Pearson's Correlation Between Chemical Composition and Higher Heating Value

		TE	L	HL	αC	HC	AC	HHV
TE	r	1.000	0.106	0.134	-0.182	0.233	-0.617	0.582
	p		0.419	0.307	0.165	0.074	< 0.0001	< 0.0001
L	r	0.106	1.000	0.062	-0.340	0.329	-0.008	0.226
	p	0.419		0.639	0.008	0.010	0.954	0.083
HL	r	0.134	0.062	1.000	0.067	0.507	-0.514	0.021
	p	0.307	0.639		0.609	< 0.0001	< 0.0001	0.873
αC	r	-0.182	-0.340	0.067	1.000	-0.826	0.287	-0.628
	p	0.165	0.008	0.609		< 0.0001	0.026	< 0.0001
HC	r	0.233	0.329	0.507	-0.826	1.000	-0.539	0.555
	p	0.074	0.010	< 0.0001	< 0.0001		< 0.0001	< 0.0001
AC	r	-0.617	-0.008	-0.514	0.287	-0.539	1.000	-0.575
	p	< 0.0001	0.954	< 0.0001	0.026	< 0.0001		< 0.0001
HHV	r	0.582	0.226	0.021	-0.628	0.555	-0.575	1.000
	p	< 0.0001	0.083	0.873	< 0.0001	< 0.0001	< 0.0001	

TE = total extractives; L = lignin; HL = holocellulose; αC = alpha cellulose; HC = hemicelluloses; AC = ash content; HHV = higher heating value; r = correlation coefficient; p = probability at 5%

Based on the correlations obtained and the process of selecting variables, regression models were generated, taking HHV as a dependent variable and chemical components as independent variables (Table 7). In the equations, the adjusted coefficient of determination and the significance of the parameters of each equation were analyzed. Taking independently in each equation total extractives content, ash content, and alpha cellulose percentage, low adjustments were obtained but with high significance in the parameters of the equations. However, when the other chosen variables (total extractives and cellulose) were included in the model, the adjustment improved (R^2 = 0.608), with significant parameters in the model.

On the basis of these results, it is considered possible to estimate HHV by means of a wood's chemical components, in the way described by Ngangyo-Heya *et al*. (2016), who obtained significant models using calorific value, extractives content, and lignin. Likewise, Martínez-Pérez *et al*. (2012) reported that their model worked well when correlating calorific value and ash content (R^2 = -0.73).

Table 7. Linear Regression Equations Between Higher Heating Value and Selected Chemical Components

Independent Variable	Model	Parameters	*Pr* > |*t*|	R^2
HHV, AC	PCS = β0 + β1 × CC	β0 = 20.382 β1 = -0.558	< 0.0001 < 0.0001	0.3193
HHV, TE	PCS = β0 + β1 × TE	β0 = 19.393 β1 = 0.039	< 0.0001 < 0.0001	0.328
HHV, αC	HHV = β0 + β1 × αC	β0 = 23.527 β1 = -0.059	< 0.0001 < 0.0001	0.384
HHV, αC, TE	HHV = β0 + β1 × αC + β2 × TE	β0 = 22.582 β1 = -0.051 β2 = 0.032	< 0.0001 < 0.0001 < 0.0001	0.608
HHV, αC, TE, AC	HHV = β0 + β1 × αC + β2 × TE + β2 × AC	β0 = 22.642 β1 = -0.0475 β2 = 0.024 β3 = -0.199	< 0.0001 < 0.0001 0.0007 0.0514	0.620

HHV = high heating value; AC = ash content; TE = total extractives; αC = alpha cellulose; β0, β1, β2, and β3 = parameters of models; R^2 = determination coefficient adjusted; Pr = probability

CONCLUSIONS

1. The chemical composition of the wood of five tree species presented a high content of polysaccharides, which indicated good performance of these species in cellulose pulp production.
2. The extractives content in *A. xalapensis* and *P. serotina* pointed to high natural durability, while the low ash content confirmed in these two species was reflected in their high calorific value.
3. A positive correlation was obtained between HHV and total extractives content, while a negative correlation was found between HHV and ash.
4. The model obtained by regression that included ash and total extractives as independent variables presented a good adjusted regression (R^2 = 0.608), with significance in its parameters, meaning that it can be used to estimate calorific value based on these variables.

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