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CALORIFIC VALUE AND INORGANIC MATERIAL OF TEN MEXICAN WOOD SPECIES

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This article is dedicated to Gerd Wegener on the occasion of his retirement as professor at the Technische Universität München.

ABSTRACT

The calorific value and ash content of bark, sapwood and heartwood of ten tree species (*Agarista mexicana, Arbutus glandulosa, A. xalapensis, Clethra macrophylla, Eucalyptus citriodora, E. robusta, E. saligna, Persea americana, Prosopis laevigata, Schinus molle*) were determined. The ash was analyzed by means of x-ray. The calorific value ranged from 15.01 to 18.87 $MJ.kg^{-1}$ for bark, from 15.01 to 18.89 $MJ.kg^{-1}$ for sapwood and from 17.40 to 419.11 $MJ.kg^{-1}$ for heartwood. The bark contained between 0.83 and 3.6 % ash, the sapwood contained 0.25 to 3.54 % ash, and the heartwood contained between 0.22 and 2.1 % ash. In general, the calorific value followed the trend: heartwood > sapwood > bark, while the mean ash percentage followed the reverse order. There was a negative correlation between ash content and calorific value. Common chemical elements present in all ash samples included calcium, potassium, magnesium and phosphorus. Heavy metals were not detected in bark or wood samples.

KEYWORDS: Hardwoods, calorific value, ash content, inorganic substances, x-ray.

INTRODUCTION

Wood is principally composed of polysaccharides and lignin, but also contains substances known as extractives and inorganic substances. Wood and bark have historically played an important role in human development as a source of heat energy through combustion, pyrolysis, gasification or liquefaction (Fengel and Wegener 1984). The calorific value is the amount of energy produced per unit mass or volume during complete combustion and is generally reported in units of calories, joule or British thermal units (BTUs). The calorific value is species dependent and ranges between 18.7 to 22.7 $MJ.kg^{-1}$ (Fengel and Wegener 1984).

Inorganic substances are obtained after subjecting the organic material to a calcination process (ASTM 1981; TAPPI 2000a) and, are collectively known as ash. The amount and chemical composition of ash depends on species, age, weather and harvest season (Kollmann 1959) as well as soil type, position in stem sap-or heartwood branches, roots (Pereira 1988). The ash content is typically between 0.1 and 1.0 %, but there are exceptions with relatively high values (Fengel and Wegener 1984). The inorganic substances present in the ash may be identified and quantified using techniques such as traditional gravimetric and/or volumetric methods, spectrophotometric methods, neutron activation analysis, or x-ray analysis (Browning 1967; Meyer and Langwig 1973; Osterhaus et al. 1975; Cutter et al. 1980). The most common elements in wood and bark are calcium, potassium, magnesium, and phosphorus. Other constituents include anions and trace of rare earths elements (Young and Guinn 1966; Cutter et al. 1980; Fengel and Wegener 1984; Fakankun and Loto 1990; Rutiaga and García 1999; Villaseñor and Rutiaga 2000).

The inorganic chemical composition of wood and other lignocellulosic species is important for a variety of reasons, including plant nutrition, the relationship to the chemical composition of surrounding soil, and the effect of mineral substances on growth and development of wood-destroying microorganisms. The latter aspect is important in the study of resistance to damage caused by insects and marine borers (Browning 1967). Ash content and composition also affect mechanical wood processing, where high ash contents may cause deterioration of cutting tools.

Lignocellulosic materials are currently important in the development of environment friendly energy supply alternatives as a short- or medium- term substitute for all or part of the fossil fuels now used. Others workers have suggested that bioethanol is a clean fuel whose use will help reduce the climate change caused by combustion of petroleum and coal (Chang 2007). Waste forest biomass and annual plants may play an important role in bioethanol production. In our locale it is common to use forest biomass waste for energy purposes, although the wood burning produces small particles (Caseiro et al. 2009), the advantage that the low sulfur content of this material results virtually none of the SO_x combustion products produced during combustion of oil and its derivatives. Considering this, and also that there is little information available on these wood species, the objective of this research was to determine the calorific value and ash content of several different wood species and to determine the inorganic elements presents in the ash.

MATERIAL AND METHODS

Wood

Wood samples were collected from in summer just before the rains start, 10 tree species (Tab. 1) in the municipality of Morelia, Michoacán, México. Morelia is situated 1920 m above sea level (19° 42' N latitude and 101° 11´ W longitude). The climate is sub-humid temperature, with an annual precipitation between 600 and 1.500 mm, and a temperature range of 12 to 22°C (INEGI 2014). The collected samples were separated into bark, sapwood and heartwood and dried outdoors, then milled. The resulting wood meal was sieved (Sieve Montinox, ISO 9002 1994) to obtain mesh 40 material (420 microns). This material was stored in sealed plastic bag, until use. Before carrying out the calcination process, the moisture content of each sample was determined using the T 264 cm-97 method (TAPPI 2000b).

Tab. 1: Tree species investigated.

Scientific name	Common name in Mexico	Family
Agarista mexicana var. *mexicana* Judd.	Palo borrego	*Ericaceae*
Arbutus glandulosa Mart. et Gal.	Madroño	*Ericaceae*
Arbutus xalapensis H.B.K.	Madroño	*Ericaceae*
Clethra macrophylla Mart. et Gal. A. DC.	Jaboncillo	*Clethraceae*
Eucalyptus citriodora Hook	Eucalipto limón	*Myrtaceae*
Eucalyptus robusta Smith	Eucalipto del pantano	*Myrtaceae*
Eucalyptus saligna Smith	Eucalipto azul	*Myrtaceae*
Persea americana Mill.	Aguacate	*Lauraceae*
Prosopis laevigata (H. & B.) Jonhst.	Mezquite	*Fabaceae*
Schinus molle L.	Pirul, falso pimentero	*Anarcandiaceae*

Calorific value

Pellets were formed from 1.0 g (dry weight) samples using a laboratory press at a pressure of 1.000 $kg.cm^{-2}$. The calorific value of these samples was determined using the T Parr 1341 ns-78 method (TAPPI 2000c) in a bomb calorimeter (Parr Model 6772). The samples were conditioned to an average moisture content of 8 %.

Inorganic substances (ash)

To determine the ash content, the wood samples were subjected to calcination in a muffle furnace (Lindberg SB) at 525°C according to the T 211 om-93 procedure (TAPPI 2000a).

Ash analysis

Microanalysis of the ash was carried out in an X-ray spectrometer, coupled to a scanning electron microscope (Jeol JSM-6400) using 20 kV acceleration voltage and 8.5 seconds sampling time (Téllez et al. 2010).

Statistical analysis

All analyses were carried in duplicate. Statistical processing was performed using the Statgraphics Plus 4.0 software. Analysis of variance (Anova) was used to identify statistical differences in the samples in relation to their calorific value and ash content (95 % confidence level). The test of multiple ranges of the least significant difference was also applied (LSD).

RESULTS AND DISCUSSION

Calorific value

Analysis of variance for all samples studied revealed p value of 0.1072 ($p \geq 0.05$), indicating that the calorific values of heartwood (18.62 $MJ.kg^{-1}$) and sapwood (17.88 $MJ.kg^{-1}$) were statistically equal, as well as the values of sapwood (17.88 $MJ.kg^{-1}$) and bark (17.64 $MJ.kg^{-1}$), as is evident from a plot on mean values (Fig. 1) and the results of multiple range tests (Tab. 2); only the calorific value of heartwood (18.62 $MJ.kg^{-1}$) and bark (17.64 $MJ.kg^{-1}$) were statistically different (Tab. 2). The greatest calorific value was obtained from heartwood samples and the lowest was obtained from bark samples (Fig. 1), which may be because heartwood is rich in extractives (Fengel and Wegener 1984) that help to slightly increase the calorific value (Kollmann 1959; White 1987; Kataki and Knower 2001).

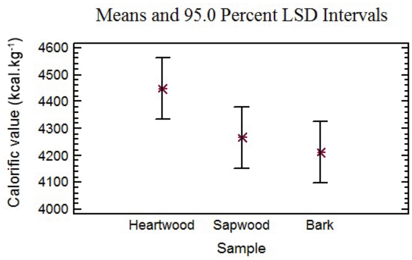

Fig. 1: Means calorific values for all wood species.

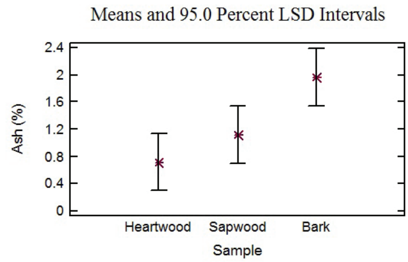

Fig. 2: Means values of ash for all wood species.

Tab. 2: Multiple range test results for calorific value.

Method: 95.0 percent LSD					
	Count	**Mean**	**Homogeneous Groups**		
Bark	10	17.638	X		
Sapwood	10	17.866	X	X	
Heartwood	10	18.62		X	
Contrast			**Difference**		**+/- Limits**
Heartwood – Sapwood			0.754		0.955524
Heartwood – Bark			*0.982		0.955524
Sapwood – Bark			0.228		0.955524

* denotes a statistically significant difference.

Tab. 3 contains the calorific values and standard deviations for the bark samples, which ranged from 15.00 MJ.kg^{-1} for *Prosopis leavigata* to 18.87 MJ.kg^{-1} in *Clethra macrophylla*. The average calorific value for the bark samples was 17.64 MJ.kg^{-1}, which is similar to previously reported values 18.77 MJ.kg^{-1}) for bark (Kollmann 1959) and falls within the range (17.55 – 19.72 MJ.kg^{-1}) reported for barks from various species (Puri et al. 1994) and for eucalyptus bark (14.07 to 18.10 MJ.kg^{-1}) (Pedraza et al. 2007).

Tab. 3: Calorific values of wood samples.

Scientific name	**Calorific value (MJ.kg^{-1})**		
	Bark	**Sapwood**	**Heartwood**
Agarista mexicana	18.14 ± 0.06Aa	18.17 ± 0.05Aa	19.07 ± 0.07Ba
Arbutus glandulosa	18.32 ± 0.02Aa	18.25 ± 0.06Ab	19.11 ± 0.04Ba
Arbutus xalapensis	18.66 ± 0.05Ab	18.24 ± 0.06Ac	19.08 ± 0.04Ba
Clethra macrophylla	18.87 ± 0.05Ad	18.89 ± 0.01Ac	19.08 ± 0.04Ba
Eucalyptus citriodora	18.53 ± 0.04Ae	18.70 ± 0.04Bd	18.73 ± 0.03Bc
Eucalyptus robusta	16.52 ± 0.03Af	17.14 ± 0.03Be	18.24 ± 0.06Cd
Eucalyptus saligna	16.69 ± 0.04Ag	17.62 ± 1.29Bf	18.55 ± 0.04Be
Persea americana	18.59 ± 0.05Ah	18.62 ± 0.05Ag	18.65 ± 0.04Af
Prosopis laevigata	15.00 ± 0.03Ai	15.00 ± 0.07Ah	18.31 ± 0.04Bg
Schinus molle	17.08 ± 0.05Aj	17.17 ± 0.06Ae	17.40 ±0.04Bh

Values with different uppercase literals in line are statistically different ($p \leq 0.05$)

Values with different lowercase literals in column are statistically different ($p \leq 0.05$)

In the case of sapwood the lowest heating value was 15.00 $MJ.kg^{-1}$ in *Prosopis leavigata* and the highest was 18.89 $MJ.kg^{-1}$ in *Clethra macrophylla*; for heartwood the minimum value was obtained from *Schinus molle* (17.40 $MJ.kg^{-1}$) and the greatest was 19.11 $MJ.kg^{-1}$ from *Arbutus glandulosa*. The average value for sapwood was 17.88 $MJ.kg^{-1}$ and for heartwood was 18.62 $kMJ.kg^{-1}$ (Tab. 2). Averaging the values from samples of sapwood and heartwood yielded an average value of 18.25 $kMJ.kg^{-1}$, which is similar to the 18.10 $MJ.kg^{-1}$ reported as an average for hardwoods (Kollmann 1959).

Several studies have reported ranges of heating value for woods in general (17.00 – 23.00 $MJ.kg^{-1}$) (FAO 1991), (15.1 – 19.7 $MJ.kg^{-1}$) (Camps and Marcos 2008), for pine species (15.4 to 18.1 $MJ.kg^{-1}$), and for oak (13.8 to 23.3 $MJ.kg^{-1}$) (Camps and Marcos 2008). The variability in these results indicates that the calorific value is species dependent, and the results discussed here fall within these reported ranges. The variations in the calorific values of wood species probably mirror differences in their chemical compositions. Previous studies have reported that higher concentrations of extractives and lignin result in greater calorific value (White 1987; Kataki and Knower 2001). However, data on the chemical composition of most of the wood species in this study were not readily available, which makes it difficult to draw firm conclusions.

The calorific values were generally lower in bark samples and the heartwood values were higher than sapwood values (Fig. 1). This is consistent with the findings of Senelwa and Sims (1999), Shanavas and Kumar (2003) and Martínez et al. (2012). While the higher calorific value for heartwood may be explained by the amounts of lignin and extractives present relative to the polysaccharide content (Kollmann 1959; Kataki and Knower 2001), in the absence of data on chemical composition of the present species/tissue types it is difficult to rationalize the higher calorific value of sapwood versus bark. However, it is expected that chemical composition of each tissue-types may differ substantially between species and that the sapwood may contain higher extractives than heartwood (Rutiaga 2001), which is important in establishing the calorific value (Fengel and Wegener 1984; White 1987). Location and/or seasonal variations in the ratio between low- and high- energy components in plant tissue due to variations in physiological and growth processes are also likely (Puri et al. 1994). Another possible explanation for species and tissue-type variations in calorific value is that such variations reflect inherent differences in physical properties of fuel material such as ash percentage, specific gravity and moisture content (Shanavas and Kumar 2003).

Inorganic substances (ash)

Statistical analysis for all samples studied revealed a p value of 0.0163 ($p \le 0.05$), indicating that statistically significant differences exist in the ash content of the samples. The difference was apparent between bark (1.97 %) and sapwood (1.12 %), between bark (1.97 %) and heartwood (0.72 %), but not between heartwood (0.72 %) and sapwood (1.12 %), as indicated by the mean plot (Fig. 2) and multiple ranges tests (Tab. 4). Bark samples had a greater content of ash than sapwood or heartwood samples, which is consistent with the results of previous workers (Kollmann 1959; Young and Guinn 1966; Bedner and Fengel 1974, Fengel and Wegener 1984; Rutiaga 2001; Shanavas and Kumar 2003).

Tab. 4: Multiple range test results for ash content.

Method: 95.0 percent LSD					
	Count	Mean	Homogeneous Groups		
Heartwood	10	0.719	X		
Sapwood	10	1.118	X		
Bark	10	1.967		X	
Contrast			Difference		+/- Limits
Heartwood – Sapwood			-0.399		0.842755
Heartwood – Bark			*-1.248		0.842755
Sapwood – Bark			*-0.849		0.842755

* denotes a statistically significant difference.

Obtained results for quantity of present minerals in bark show values that range from 0.83 in *Clethra macrophylla* to 3.6 % in *Prosopis leavigata* (Tab. 5), and the average (1.97 %) was within the range (1.1 to 7.3 %) reported by Fengel and Wegener (1984) for bark. However, higher values have been reported (Shanavas and Kumar 2003).

In the case of sapwood, the results varied between 0.25 in *Clethra macrophylla* to 3.54 % in *Prosopis leavigata*. For heartwood, the lowest value (0.22 %) was obtained from *Clethra macrophylla* and a maximum of 2.1 % was observed in *Schinus molle* (Tab. 5). By averaging the results of the sapwood and heartwood measurements values of 0.72 and 1.12 % were obtained, respectively (Tab. 4). These are within the range (0.1 to 1.0 %) reported for hardwoods (Fengel and Wegener 1984).

Tab. 5: Ash content of wood samples.

Scientific name	Ash (%)		
	Bark	Sapwood	Heartwood
Agarista mexicana	1.46 ± 0.08Aa	0.64 ± 0.00Ba	0.28 ± 0.01Ca
Arbutus glandulosa	1.58 ± 0.11Ab	0.52 ± 0.02Bb	0.26 ± 0.01Cb
Arbutus xalapensis	1.08 ± 0.01Ac	0.50 ± 0.02Bb	0.36 ± 0.01Cc
Clethra macrophylla	0.83 ± 0.00Ad	0.25 ± 0.01Bc	0.22 ± 0.01Cd
Eucalyptus citriodora	1.44 ± 0.00Aa	0.34 ± 0.01Bd	0.48 ± 0.01Ce
Eucalyptus robusta	3.05 ± 0.02Ae	2.28 ± 0.09Be	1.25 ± 0.00Cf
Eucalyptus saligna	2.93 ± 0.00Af	0.48 ± 0.01Bb	0.58 ± 0.00Cg
Persea americana	1.43 ± 0.04Aa	0.47 ± 0.01Bb	0.42 ± 0.00Bh
Prosopis laevigata	3.60 ± 0.02Ag	3.54 ± 0.00Af	1.24 ± 0.02Bf
Schinus molle	2.27 ± 0.00Ae	2.16 ± 0.00Be	2.10 ± 0.00Ci

Values with different uppercase literals in line are statistically different (p≤0.05)

Values with different lowercase literals in column are statistically different (p≤0.05).

Increasing ash content had a negative effect on calorific value and provides a reasonable explanation for the observed variations in combustion values. This is consistent with previous works (Fengel and Wegener 1984; Bhatt and Todaria 1992; Kataki and Konwer 2001; Shanavas and Kumar 2003). Species with low ash percentage such as *Agarista mexicana, Arbutus xalapensis, A. glandulosa* and *Clethra macrophylla* concomitantly yielded higher calorific values. This was observed in bark (Fig. 3), sapwood (Fig. 4), and heartwood (Fig. 5).

In general, calorific value followed the sequence heartwood > sapwood > bark, while mean ash percentage followed the reverse order (bark > sapwood > heartwood). The same trend was noted by Shanavas and Kumar (2003) in a selection of Indian wood species.

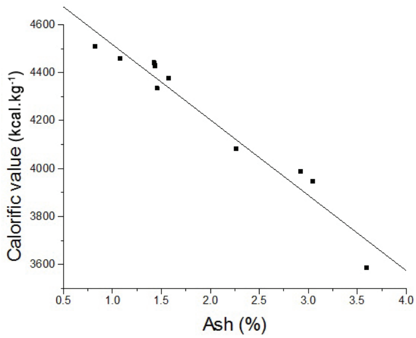

Fig. 3: Correlation of ash and calorific value in bark samples.(Y = 20.22 – 1.31X, r = -0.97).

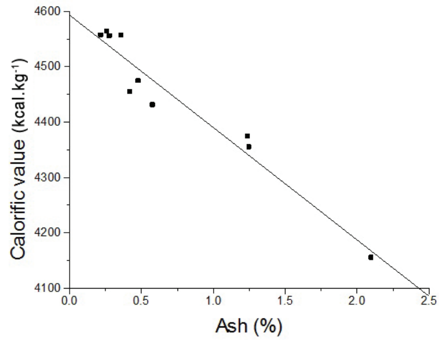

Fig. 4: Correlation of ash and calorific value in sapwood samples. (Y = 19.00 – 1.01X, r = -0.97).

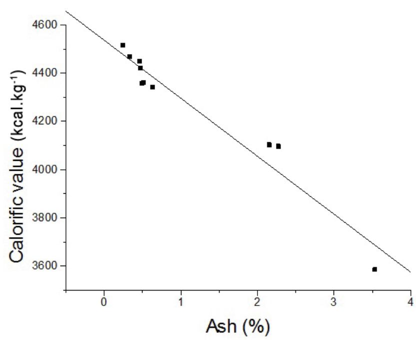

Fig. 5: Correlation of ash and calorific value in heartwood samples. (Y = 19.23 – 0.84X, r = -0.97).

Ash analysis

The results of x-ray ash analysis are provided in Tab. 6 (the letters nd indicate the element was not detected). The analysis indicated the presence of 10 chemical elements in bark and 9 in sapwood and heartwood. Concentrations varied between 0.02 % for aluminum in the heartwood of *Prosopis leavigata* to 93.99 % for calcium in the sapwood of *Schinus molle*. However, variations were observed in the quantity of each element in the samples. For example, in some woods only 5 elements were detected (*Agarista mexicana*, *Eucalyptus citriodora*, *E. robusta* and *E. saligna*), while 10 elements were found in the heartwood of *Schinus molle*. Fluoride was not detected in either sapwood or heartwood, only in the barks of *Prosopis leavigata* and *Schinus molle*.

Tab. 6: Chemical elements detected in wood species (%).

Agarista mexicana			
Element	**Bark**	**Sapwood**	**Heartwood**
Magnesium	10.87 ± 0.33	9.31 ± 0.37	11.68 ± 0.31
Phosphorus	1.23 ± 0.23	1.42 ± 0.23	0.78 ± 0.24
Potassium	22.53 ± 0.22	14.51 ± 0.22	15.68 ± 0.24
Calcium	57.86 ± 0.20	68.17 ± 0.21	64.84 ± 0.21
Manganese	7.52 ± 0.20	6.59 ± 0.18	7.03 ± 0.21
Arbutus glandulosa			

Sodium	1.07 ± 0.20	0.96 ± 0.18	nd
Magnesium	1.93 ± 0.18	1.96 ± 0.18	3.77 ± 0.20
Silicon	nd	nd	0.22 ± 0.20
Phosphorus	1.97 ± 0.18	1.39 ± 0.21	1.28 ± 0.20
Sulfur	1.17 ± 0.17	1.59 ± 0.18	1.99 ± 0.20
Potassium	15.98 ± 0.17	15.14 ± 0.17	26.97 ± 0.18
Calcium	77.88 ± 0.18	78.96 ± 0.18	65.77 ± 0.18
Arbutus xalapensis			
Magnesium	12.62 ± 0.18	25.47 ± 0.20	7.32 ± 0.18
Aluminum	0.30 ± 0.18	nd	nd
Silicon	4.50 ± 0.18	nd	8.43 ± 0.20
Phosphorus	9.28 ± 0.17	5.94 ± 0.18	4.58 ± 0.20
Sulfur	nd	1.43 ± 0.20	nd
Potassium	33.72 ± 0.16	8.19 ± 0.18	55.86 ± 0.17
Calcium	39.58 ± 0.17	46.73 ± 0.16	16.01 ± 0.17
Manganese	nd	12.23 ± 0.15	7.80 ± 0.16
Clethra macrophylla			
Magnesium	13.42 ± 0.17	7.20 ± 0.18	6.86 ± 0.17
Aluminum	1.85 ± 0.18	nd	nd
Silicon	5.79 ± 0.20	nd	nd
Phosphorus	4.96 ± 0.16	2.40 ± 0.16	1.24 ± 0.16
Potassium	25.62 ± 0.16	19.04 ± 0.16	29.83 ± 0.16
Calcium	48.36 ± 0.17	61.18 ± 0.14	50.32 ± 0.18
Manganese	nd	10.18 ± 0.18	11.75 ± 0.17
Eucalyptus citriodora			
Magnesium	30.52 ± 0.14	4.29 ± 0.17	3.84 ± 0.17
Phosphorus	12.02 ± 0.18	0.88 ± 0.17	0.67 ± 0.18
Potassium	6.96 ± 0.17	5.70 ± 0.18	15.63 ± 0.14
Calcium	50.50 ± 0.14	83.48 ± 0.14	71.94 ± 0.14
Manganese	nd	5.65 ± 0.17	7.92 ± 0.17
Eucalyptus robusta			
Magnesium	10.94 ± 0.13	2.02 ± 0.14	1.95 ± 0.14
Phosphorus	9.63 ± 0.14	0.74 ± 0.14	0.77 ± 0.14
Potassium	15.52 ± 0.13	12.98 ± 0.13	26.84 ± 0.14
Calcium	63.88 ± 0.13	79.88 ± 0.13	62.53 ± 0.13
Manganese	0.03 ± 0.02	4.38 ± 0.17	7.91 ± 0.16
Eucalyptus saligna			
Magnesium	15.73 ± 0.14	3.29 ± 0.17	3.06 ± 0.16
Phosphorus	11.34 ± 0.14	1.09 ± 0.14	1.84 ± 0.14
Potassium	15.39 ± 0.17	9.88 ± 0.14	22.91 ± 0.16
Calcium	57.54 ± 0.16	80.75 ± 0.13	64.33 ± 0.13
Manganese	nd	4.99 ± 0.13	7.86 ± 0.13
Persea americana			
Sodium	7.05 ± 0.17	6.36 ± 0.13	6.07 ± 0.13
Magnesium	10.49 ± 0.17	9.01 ± 0.16	9.73 ± 0.14
Aluminum	0.36 ± 0.14	0.29 ± 0.13	0.15 ± 0.01
Silicon	1.33 ± 0.14	2.01 ± 0.13	1.09 ± 0.13
Phosphorus	5.28 ± 0.17	4.88 ± 0.16	5.12 ± 0.16
Sulfur	2.09 ± 0.14	1.35 ± 0.14	2.17 ± 0.14
Cloro	0.54 ± 0.13	0.10 ± 0.01	0.17 ± 0.13
Potassium	37.64 ± 0.16	37.73 ± 0.16	39.19 ± 0.14
Calcium	35.22 ± 0.13	38.27 ± 0.14	36.31 ± 0.16

Prosopis laevigata			
Fluoride	5.54 ± 0.13	nd	nd
Sodium	2.08 ± 0.18	nd	5.21 ± 0.14
Magnesium	8.39 ± 0.17	2.96 ± 0.17	9.30 ± 0.16
Aluminum	nd	0.29 ± 0.13	0.02 ± 0.01
Silicon	nd	1.44 ± 0.17	0.89 ± 0.13
Phosphorus	19.47 ± 0.18	1.25 ± 0.14	4.99 ± 0.16
Sulfur	0.37 ± 0.13	0.63 ± 0.14	1.85 ± 0.14
Potassium	26.54 ± 0.18	12.12 ± 0.14	39.67 ± 0.17
Calcium	37.70 ± 0.13	81.31 ± 0.14	38.07 ± 0.13
Schinus molle			
Fluoride	5.83 ± 0.18	nd	nd
Sodium	nd	nd	0.37 ± 0.13
Magnesium	3.78 ± 0.18	2.05 ± 0.17	3.45 ± 0.18
Aluminum	0.15 ± 0.13	nd	0.87 ± 0.01
Silicon	0.78 ± 0.11	0.50 ± 0.13	3.38 ± 0.14
Phosphorus	2.60 ± 0.17	1.25 ± 0.17	3.08 ± 0.16
Sulfur	1.38 ± 0.18	0.18 ± 0.13	1.87 ± 0.16
Chlorine	0.26 ± 0.13	nd	0.43 ± 0.13
Potassium	35.57 ± 0.13	2.03 ± 0.13	39.84 ± 0.16
Calcium	49.65 ± 0.13	93.99 ± 0.16	46.71 ± 0.13

In bark samples the least abundant element was manganese with a value of 0.03 % in *Eucalyptus robusta*, and the element present in the highest concentration was calcium at 77.88 % in *Arbutus glandulosa*. For sapwood, the lowest concentration detected was for chlorine (0.10 % in *Persea americana*) and the highest was calcium in *Schinus molle* (93.99 %). The lowest concentration element in heartwood was 0.02 % aluminum in *Prosopis leavigata* and highest was 71.94 % calcium in *Eucalyptus citriodora*. The most common chemical elements detected were calcium, potassium, magnesium and phosphorus, which are common elements, found in wood (Cutter et al. 1980; Fengel and Wegener 1984).

Most of the elements detected in these samples have been reported in other woods. For example, calcium, potassium, magnesium, manganese, sodium, chlorine, phosphorus, aluminum, iron, and zinc were detected in several conifers and hardwoods (Young and Guinn 1966; Cutter et al. 1980); sodium, potassium, calcium, magnesium, manganese, zinc, and phosphorus were detected in the bark and wood of various hardwoods (Choong et al. 1976); barium, tin, copper, cerium, erbium, cesium, and antimony were found in the heartwood of *Dalbergia granadillo* and of *Platymiscium lasiocarpum* (Rutiaga and García 1999), barium and iron were detected in wood of *Casuarina equisetifolia* (Villaseñor and Rutiaga 2000); calcium, potassium, sulfur, phosphorus, silicon, and magnesium were observed in several wood species (Rutiaga 2001); and even rare earths metals have been detected in wood samples (Young and Guinn 1966; Meyer and Langwig 1973; Villaseñor and Rutiaga 2000).

Inorganic substances play an important role as nutritional elements for trees growth (Fengel and Wegener 1984; Scheffer and Schachtschabel 1998) and the elements detected in these samples are precisely those chemical elements common in vascular plants (Gil 1994).

CONCLUSIONS

Variations abound in the combustion characteristics of tree species and tissue-types (bark, sapwood, or heartwood), and the values reported for a particular species reflect only the samples tested and not the entire population.

In general, wood species/tissue-types with low ash content are favored as fuels, as they show better combustion characteristics. Based on the calorific value, preferred species include *Clethra macrophylla, Arbutus xalapensis, A. glandulosa, Persea americana,* and *Agarista mexicana*. However, factors such as specific gravity, drying properties, rapidity of burning, ease and completeness of combustion, and emission characteristics are probably equally important, In general, calorific value followed the sequence heartwood > sapwood > bark, while mean ash percentage followed the reverse order.

Using x-ray analysis ten chemical elements, in clean elementary form, were detected in bark and nine were detected in sapwood and heartwood. The presence of chemical elements in the studied wood species was not homogeneous, this could be associated to the metabolism of each tree species. The greatest concentration observed was calcium in the sapwood of *Schinus molle* (93.99 %) and the lowest was aluminum in the heartwood of *Prosopis leavigata* (0.02 %). Heavy metals were not detected in the wood samples.

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