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Wood characterization for energy application proceeding from pruning *Morus alba* L., *Platanus hispanica* Münchh. and *Sophora japonica* L. in urban areas

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ABSTRACT

Pruning urban forests generates significant amounts of lignocellulosic biomass every year. The energy potential of this biomass is unclear. The aim of this research was direct analysis of the gross calorific value (GCV), elemental composition and moisture content of *Morus alba* L., *Platanus hispanica* Münchh. and *Sophora japonica* L. by means of laboratory equipment. This analysis allowed for further development of indirect GCV prediction models which are economically attractive and less time consuming to direct analysis. These models presented high coefficients of determination (R^2 0.66–0.96). It has been determined that the species with highest mean GCV is *S. japonica* L. (19615.68 kJ/kg-dry sample) whereas the one with the lowest is the *M. alba* L. (18192.87 kJ/kg-dry sample). Elemental analysis showed highest carbon (48.22%), hydrogen (6.17%) and nitrogen (1.16%) content in *S. japonica* L. in dry samples. Sulfur was constant at the level 0.05% for all analyzed species. Also percentage of bark and wood density were determined. Mean percentage of bark was highest for *P. hispanica* Münchh. (13.05%) while wood density was highest for *S. japonica* L. (0.86 g cm^{-3}). This way the research has proven that the biomass produced by pruning urban forests appears to be an interesting source of renewable energy.

1. Introduction

Numerous researchers have published mathematical models for predicting the calorific value of various biomass materials from the concentration of the main elements, such as percentage of carbon, hydrogen, nitrogen and others [1–3]. Models have been also derived from proximate analysis [4–6]. The indirect calculation of calorific value with this type of models is justified by the high cost of employing a calorimetric bomb [7–9]. The calorific value is constant for each material with defined elemental composition. The moles of each component in a sample are obtained by multiplying the sample weight by the weight percentage of each, divided by the atomic weight of each element being able to obtain its empirical formula $CH_wO_xN_yS_z$, where w is the number of moles of hydrogen per mole of carbon; x is the number of moles of oxygen per mole of carbon; y is the number of moles of nitrogen per mole of carbon; z is the number of moles of sulfur per mole of carbon. In other words, the values of w, x, y and z are obtained by dividing the moles of each element contained in the sample by the moles of carbon. Based on these values a specific calorific value for dry material is given.

When measuring the calorific value of biomass, it has to be taken into account that it is a porous material with the ability of retaining water. Moreover, the moisture content of the material is likely to change its empirical formula and the gravimetric percentages of C, H, O and N. Therefore, standards for determining the calorific value for a particular material, such as UNE 164001:2005 EX [10], point to that it should be determined in the anhydrous state, in dry basis. In this state (without water), the calorific value of a material with defined composition would be constant and determination of indirect prediction models would not be applicable. Nevertheless, such models can be found very useful when the empirical composition varies in humidity, presence or absence of foliage, bark percentage or, when it comes to obtaining the calorific value of an indeterminate mixture of materials.

The development of mathematical models for indirect determination of the calorific value is useful in materials that may have

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variability in composition, and there is some uncertainty concerning the conditions of use, or the proportion in the mixture of materials. For that, economical and reliable methods are required. Such situation is commonly observed in the industrial field. For that, researchers as Jenkins et al. [11], Yin [6] and Callejón-Ferre et al. [7,8] provide models for specific types of mixtures.

Usually, the received biomass for combustion in industrial facilities is found with some moisture. Since forced drying processes excessively raise production costs, they are rarely used in the production of energy. Air drying rarely decreases moisture content below 20% in Mediterranean conditions [12–14]. Moreover, it is common that biomass power plants not only work with a well-defined type of material but also with variable mixtures of different types of biomass. For these reasons the composition of biomass used in industry has variability that directly influences the expected calorific value. The uncertainty of calorific value causes that its determination before the introduction of the materials in the boiler would be meaningful for understanding its energy performance. If the direct determination of the calorific value by means of a calorimetric bomb is more expensive than the determination of the composition, as demonstrated in this work, the development of indirect prediction models for calorific value from the percentage of the different elements is fully justified.

Large quantity of residual biomass with potential energy and industrial end can be obtained from management operations of urban forests. The profitability of exploiting these resources is conditioned by the amount of existing biomass within urban community ecosystems, whose methods of quantification have been studied by Sajdak and Velazquez [15] and Velázquez et al. [16]. These researches point to the residual biomass which can be obtained by pruning of one tree. The obtained averages are 31.67 kg dry biomass/tree of *Morus alba* L. located in street; 77.78 kg dry biomass/tree of *M. alba* L. located in the park; 23.98 kg/tree of *Platanus hispanica* Münchh; and 18.07 kg/tree of *Sophora japonica* L. Whole calculation of the residues in a city will depend on the inventory of each city. Therefore we cannot predict exactly. The aim of this research was focused on direct and indirect measurement of energy characteristics of lignocellulosic waste from urban tree pruning.

2. Materials and methods

2.1. Vegetal material

The species analyzed in this work were mulberry (*M. alba* L.), *P. hispanica* Münchh. and *S. japonica* L., which are very popular ornamental trees in the Mediterranean areas. *M. alba* L. known as white mulberry is a species of the family *Moraceae*, genus *Morus*; *P. hispanica* Münchh. (*Platanus acerifolia*, *Platanus hybrida*) is a tree in the family *Platanaceae*, genus *Platanus* and *S. japonica* L. also known as *Styphnolobium japonicum* and Pagoda Tree is a species in the family *Fabaceae*, genus *Styphnolobium* [17]. All species are extensively cultivated ornamental, parkland and roadside trees in the temperate regions. They are widely observed in linear plantations in streets as well as isolated trees in gardens [18].

2.2. Fuel specification

The examined biomass takes origin from pruning operations of Mulberry, Hybrid plane and Pagoda tree. The specification of biomass was based on the norm UNE-EN 14961-1 [19]. According to this norm, the classification of the origin and sources of solid biofuel examined in this work are the following:

"*1. Woody biomass*

1.1. Woody biomass from forest, plantation and other virgin wood

1.1.7. Wood from gardens, parks, maintenance of roadsides, vineyards and orchards"

According to the specification of solid biofuels based on shape and properties, the analyzed material is classified as showed in Table 1.

Table 1
Specification of properties of wood logs.

Origin: According to paragraph 6.1 and Table 1 of Ref. [19].	Woody biomass: *Morus alba* L. *Platanus hispanica* Münchh. *Sophora japonica* L.	
Commercial form	Logs, wood	
Dimensions		
Length (L) (maximum length of a single cut), cm	*Morus alba* L.	L 100+, (max. 380 cm)
	Platanus hispanica Münchh.	L 100, 100 cm ± 5 cm
	Sophora japonica L.	L 100+, (max. 180 cm)
Diameter (D) (maximum diameter of a single cut), cm	*Morus alba* L.	D 10, 2 cm $\leq$ D $\leq$ 10 cm
	Platanus hispanica Münchh.	D 10, 2 cm $\leq$ D $\leq$ 10 cm
	Sophora japonica L.	D 2–, D < 2 cm
Humidity (M) (according to received mass)%	*Morus alba*	M 45
	Platanus hispanica Münchh.	M 45
	Sophora japonica L.	M 45
Volume or weight, m^3 stacked or loose or kg as received	*Morus alba* L.	Mean dry weight 31.13 kg street^{-1} tree; 77.78 kg park tree^{-1}
	Platanus hispanica Münchh.	Mean dry weight 23.98 kg tree^{-1}
	Sophora japonica L.	Mean dry weight 18.07 kg tree^{-1}
Proportion by volume of stumps	*Morus alba* L.	Whole (unsplit)
	Platanus hispanica Münchh.	Whole (unsplit)
	Sophora japonica L.	Whole (unsplit)
Cut surface	*Morus alba* L.	Smooth and regular
	Platanus hispanica Münchh.	Smooth and regular
	Sophora japonica L.	Smooth and regular
Wet and rot	*Morus alba* L.	No
	Platanus hispanica Münchh.	No
	Sophora japonica L.	No