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Biomass yield and quality of an energy dedicated crop of poplar (*Populus* spp.) clones in the Mediterranean zone of Chile

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ABSTRACT

The biomass of nineteen *Populus* spp. clones was measured and characterized as a feedstock for energy production. Biomass yield was estimated using the average volume and dry weight of each clone. Quality traits analyzed include higher heating value (HHV) and chemical composition. Biomass yield ranged between 0.31 and 9.54 kg individual^{-1}. HHV ranged between 17.69 and 20.75 MJ kg^{-1}. Total extractives varied between 11.78% and 19.62% (mass fraction% on dry basis), Klason lignin ranged between 14.31% and 20.92% and α-Cellulose ranged between 42.38% and 48.70%, both without extractives. The ash content ranged from 2.05% to 3.40%. The chemical composition of the clones reported here is slightly different to the previously reported for this genre, but this is attributed to the juvenile wood and the inclusion of bark in the samples. As a result of the biomass used in this study, the correlations between the chemical composition and extractives content on HHV are of very poor quality. Based on our results, an approach including both biomass yield and quality is required in order to ensure the most viable treatment for a sustainable utilization of the biomass for energy generation. For a direct combustion perspective, the preferred clones are those which a high combination of yield and heating value as Bocalari, Beaupre, Constanzo and Nmdv.

1. Introduction

Among the most promissory woody species in Chile are hybrid poplars, due to their fast growth, high adaptability to a wide variety of soils and climatic conditions and wide range of potential applications as biofuels, pulp and paper, as well as other bio-based products such as chemicals and adhesives [1].

Lignocellulosic biomass is typically the fibrous and non-edible plant material composed primarily by fibers of walls formed by layers of organic macromolecules, the polysaccharides cellulose and hemicellulose and a phenolic polymer, lignin. All these macromolecules provide a strong mechanical stability due to the bonds of lignin in the cell wall, providing a natural resistance to its degradation [2] and becoming one of the main challenges for the second generation biofuel industry [3]. However, lignin contribution to the higher heating value (HHV) has been demonstrated in different species [4,5].

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Besides the structural components there are also extractives and inorganics. Extractives are a varied group of organic compounds usually represent a minor proportion of the biomass and vary with the species, structure of the plant analyzed and the solvents used for the extraction. Depending on their quantity and industrial value they could represent a potential source of co-products [1]. White [4] states that differences in HHV between softwoods and hardwoods species could be more related to the presence of extractives than to the lignin content of these groups. On the other hand, Kacik et al. [6] found that HHV in Populus depend on the content of both, lignin and extractives.

Mineral compounds or inorganics are usually informed as ash. They represent less than 1% of the dry weight (mass fraction) of woody biomass [7] and include metals and metalloids that vary in type and quantity depending on the biomass type (*i.e.* whole plants or harvest residues), plant tissue (*i.e.* wood, bark or leaves), soil type and management (*i.e.* fertilization). Their relevance depends on their quantity and composition [8,9] and, as the other chemical compounds, are used to screen biomass feedstocks for biofuel applications [1].

According to Dinus [10] and others researchers [1,7,11], in order to reduce the cost of pre-treatments and to increase the total energy produced we should select feedstocks based on the available biomass conversion technology, the end-product required and the chemical composition of the feedstock utilized. Different energy conversion processes require different biomass quality in order to reach the end product with high performance and at low cost [10].

In Chile, the most common process for energy generation with lignocellulosic biomass is combustion. A 20% of the primary energy (234 EJ) is generated from wood fuel and its derivatives to produce heat for domestic and industrial uses and electricity (900 GWh, 1.6% of the total) [12]. In the short term, the biomass participation in the energy generation matrix should increase by the adoption of short rotation lignocellulosic crops.

For the purpose of this study, nineteen *Populus* spp. clones from an energy dedicated plantation were studied as potential feedstock for combustion processes [13] and as a primary source for solid fuels like pellets. The goal of this study was the characterization of the biomass for energy purposes, thus samples used in the analyses were composed by juvenile wood and included bark.

2. Materials and methods

2.1. *Experimental site*

The plantation included nineteen two-years old *Populus* spp. clones growing in a density of 9,000plants ha^{-1} at Antumapu Experimental Station located in the Central Zone of Chile at 33°34′10″S 70°38′40″W and 368 m of altitude. The soil is a Mollisol, coarse loamy over sandy, skeletal, mixed Thermic Entic Haploxeroll, 60 cm deep, flat and well drained [14] with 28.70 mg kg^{-1} of N; 3.27 mg kg^{-1} of P; 125 mg kg^{-1} of K; 25.19 mg kg^{-1} of S; a pH of 8.24 and 2.34% of organic matter. The site has a Mediterranean semiarid climate, with 8 dry months during the warm season, a minimum temperature of 3.4 °C in July and a maximum temperature of 28.7 °C in January, with 231 frost-free days and an annual precipitation of 330 mm [15]. The trial was irrigated 3 times a week from October to March to keep the soil at field capacity.

2.2. *Biomass productivity*

Stem and branches of six random individuals of nineteen clones of *Populus* spp. were harvested manually and cut in pieces 0.5 m long. We estimated the volume of each individual geometrically multiplying the area corresponding to the average diameter of each piece by its longitude [16]. The apex was considered as a cone. Each piece was dried at 60 ± 3 °C until a constant weigh was reached and then weighted. We used the average volume and dry weight of the six individuals for the determination of the specific gravity and the total biomass per hectare of each clone.

2.3. *Higher heating value (HHV)*

The heating value (HHV) was determined in a ballistic bomb calorimeter (Gallen Kamp 23C679). Two samples of 0.5–1.0 g of each clone were weighed and ignited.

2.4. *Chemical analyses*

A sample of each clone was chipped in a hammer mill of 9.7 W and milled in a Wiley Mill N°4 to reduce the sample to dust size. Finally, part of the material was sieved to a size of 0.40 mm–0.25 mm, as described by T 264 om-88 "Preparation of Wood for Chemical Analysis" [17].

Determinations of extractives (removed sequentially with ethanol-toluene, ethanol and water and expressed as total extractives), total, Klason and soluble lignin, holocellulose, α-cellulose and ash were done in duplicate according to TAPPI and NREL procedures [18]. Hemicellulose was obtained by difference. For the determination of soluble lignin, 1 mL of the homogeneous filtrated liquor was taken in Eppendorf tubes in duplicate, and then centrifuged at 1047.2 rad $s^{-1}$for 15 min. The supernatant was separated from the pellet and taken to a Spectrometer adjusted to 240 nm, to the recommended wavelength. Then, samples were diluted to match a range between 700 and 1000 of absorbance and the absorptivity at the recommended wavelength corresponded to 2.5×10^6 L kg^{-1} m^{-1} [18].

A multiple regression analysis was carried out in JMP® 9.0.2 to detect the quality variables of the biomass (extractives, lignin, α-cellulose, holocellulose and ash) explaining its HHV.

3. Results and discussion

3.1. *Biomass productivity*

Table 1 shows the biomass productivity of the clones evaluated in this study. Biomass yield varied between 0.31 and 9.54 kg dry weight (DW) $individual^{-1}$. The most productive clones were Bocalari, Constanzo, Beaupre and Nmdv.

When extrapolated to a hectare basis, biomass yield range from 1.57 (VSB-2) to 47.7 (Bocalari) Mg DW ha^{-1} (Fig. 1). Twelve