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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

Table 1 – Biomass yield (kg dry weight (DW) individual^{-1}) of the *Populus* clones evaluated in this study (mean ± SD).

Clon	n	Yield (kg DW indiv^{-1})		Clon	n	Yield (kg DW indiv^{-1})	
Bocalari	4	9.54 ± 5.11	a	*Eridano*	3	2.47 ± 2.16	b
Constanzo	6	5.95 ± 3.71	ab	*Categoría*	10	2.18 ± 1.79	b
Beaupre	7	5.47 ± 2.58	ab	*269*	2	1.99 ± 2.63	b
Nmdv	3	4.95 ± 2.52	ab	*Carolinensis*	2	1.79 ± 2.17	b
ST-109	10	3.44 ± 2.46	b	*70038/31*	6	1.66 ± 1.32	b
Dvina	5	3.42 ± 2.47	b	*Chopa Blanca*	3	1.53 ± 1.27	b
Neva	6	3.38 ± 2.30	b	*Triplo*	3	0.79 ± 0.59	b
Unal	3	3.04 ± 3.33	b	*NM6*	3	0.73 ± 0.31	b
Boelare	7	2.78 ± 1.75	b	*VSB-2*	3	0.31 ± 0.20	b
I-488	4	2.53 ± 1.98	b				

Mean values followed by the same letters are not significantly different at $P < 0.05$.

Table 2 – Higher heating value (HHV; MJ kg^{-1}) of the *Populus* spp. clones evaluated in this study (mean ± SD).

Clon	HHV (MJkg-1)		Clon	HHV (MJkg-1)	
Neva	20.75 ± 0.52	a	*I-488*	19.59 ± 0.47	abcd
269	20.49 ± 0.16	ab	*Chopa Blanca*	19.35 ± 0.42	abcd
VSB-2	20.44 ± 1.22	ab	*70038/31*	19.26 ± 0.03	abcde
Bocalari	20.38 ± 0.22	ab	*NM6*	19.08 ± 0.45	bcde
Nmdv	20.28 ± 0.07	abc	*Categoría*	18.89 ± 0.02	bcde
ST-109	20.02 ± 0.04	abc	*Triplo*	18.88 ± 0.03	bcde
Beaupre	19.97 ± 0.01	abc	*Unal*	18.73 ± 0.45	cde
Boelare	19.86 ± 0.23	abc	*Eridano*	18.20 ± 0.42	de
Carolinensis	19.82 ± 0.48	abcd	*Constanzo*	17.69 ± 0.21	e
Dvina	19.63 ± 0.06	abcd			

Mean values followed by the same letters are not significantly different at $P < 0.05$.

of the nineteen clones studied produced more than 10 Mg DW ha^{-1}. Liesebach et al. [19] obtained similar yields in energy plantations like those used in this study. Four clones yielded more than 20 Mg DW ha^{-1}, as was reported by Liberloo et al. [20] in a high-density coppice plantation of three years old in a second rotation.

3.2. *Higher heating value (HHV)*

Results of the higher heating value (HHV) determination are shown in Table 2.

HHV varied between 17.69 and 20.75 MJ kg^{-1}. The clones with the highest HHV were Neva, 269 and VSB-2. Constanzo and Eridano showed the lowest HHV. The values presented in this work are within the range informed in previous studies on *Populus* spp. wood [21,22] and close to those reported for stem wood of two years old secondary sprouts of *Populus x euro-americana* [23].

3.3. *Extractives*

Results showed in Table 3 correspond to the extractives soluble in ethanol-toluene, ethanol and water, and total extractives in a mass fraction basis (%).

Total extractives varied between 11.78% and 19.62%. Ethanol-toluene removed close to 10% of the woody biomass. Water removed around 3% of the biomass and ethanol removed less than 1%. Total extractives values are higher than those reported for wood of broadleaf species (hardwoods) and for *Populus* spp. in particular [1,4,7,8,24]. Isenberg [25] reported extractives contents of 1.4%–2.4% in alcohol-benzene and of 3.5%–3.6% in ethanol when working on mature wood of poplar clones. Values of 1.5%–2.0% of extractives in ethanol/toluene were informed by Kacik et al. [6] in wood of *Populus* spp. from different clones. Extractives in ethanol in a range of 2.6%–3.6% for wood of seven years old *deltoides x nigra* clones were reported by Davis et al. [26]. These authors concluded that *deltoides x nigra* clones showed similar results to other hybrid poplars analyzed in previous studies. Fernandez et al. [24] obtained a range of 2.3%–4.0% (freeze dried wood) of solubles in acetone for nine clones of *Populus tremuloides* when analyzing the wood of mature trees. Luo and Polle [23] obtained between 11.2% and 12.8% of removed material in a more exhaustive extraction with water and methanol.

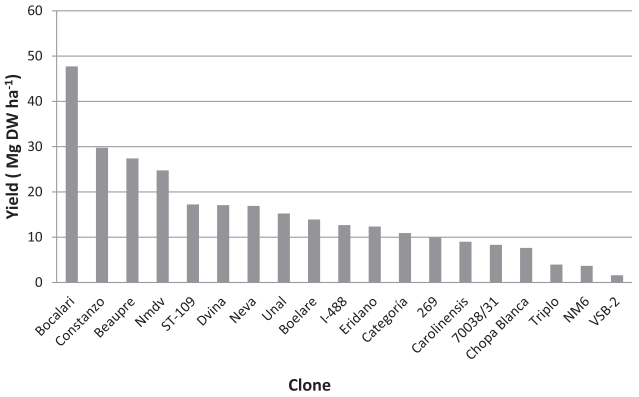

Fig. 1 – Biomass yield of the *Populus* clones evaluated in this study extrapolated to Mg dry weight (DW) ha^{-1}.

Our results are closer to those informed by Isenberg [25] for the bark of poplar clones and are in accordance with those presented by Bowersox et al. [9] who used composite samples of wood and bark from four years old hybrid poplars and using a similar method for the extractives (ASTM) to the one used in this study (TAPPI).

The difference in total extractives between this and other studies could be attributed to the presence of bark in the samples analyzed. It is well known that steam wood and bark differ on fiber structure and chemical composition, and that bark has an especially high content of extractives [11,27,28].

3.4. *Lignin*

Results of lignin determinations are shown in la Table 4.

Lignin was divided in Klason (insoluble or acid lignin) and soluble lignin. Klason lignin ranged between 14.31% and 20.92%. This range is similar to the one reported by Kacik et al. [6], who found values between 17.68% and 23.66% of Klason lignin in wood from sixteen years old *Populus* clones. However, insoluble lignin contents for most of the clones of this study were lower than 20%, the average value for hardwoods reported by Scurlock [29]. This could be attributed to the presence of bark in the samples and the use of juvenile wood.

Table 3 – Extractives in ethanol/toluene, ethanol, water and total extractives of *Populus* spp. clones a mass fraction (% on dry basis).

Clon	Ethanol/toluene (%)	Ethanol (%)	Water (%)	Total (%)	
70038/31	15.61 ± 0.08	0.38 ± 0.09	3.63 ± 0.16	19.62 ± 0.35	a
Unal	14.43 ± 0.05	0.20 ± 0.04	3.57 ± 0.07	18.20 ± 0.16	ab
Nmdv	12.06 ± 0.33	0.58 ± 0.07	4.97 ± 0.36	17.62 ± 0.62	bc
Eridano	12.61 ± 0.23	0.28 ± 0.19	4.48 ± 0.12	17.37 ± 0.16	bcd
Carolinensis	11.31 ± 0.14	0.53 ± 0.07	4.64 ± 0.90	16.48 ± 0.83	cde
NM6	11.94 ± 0.01	0.35 ± 0.01	3.59 ± 0.07	15.89 ± 0.08	def
Boelare	11.91 ± 0.13	0.43 ± 0.07	3.04 ± 0.14	15.38 ± 0.20	efg
Constanzo	9.49 ± 0.17	0.77 ± 0.03	4.46 ± 0.41	14.73 ± 0.55	fgh
Beaupre	9.78 ± 0.01	0.75 ± 0.09	4.00 ± 0.40	14.53 ± 0.30	fgh
Bocalari	10.95 ± 0.10	0.43 ± 0.27	3.14 ± 0.03	14.53 ± 0.34	fgh
269	10.90 ± 0.14	0.55 ± 0.08	2.92 ± 0.04	14.37 ± 0.27	fgh
Triplo	10.64 ± 0.37	0.46 ± 0.09	3.05 ± 0.30	14.16 ± 0.02	ghi
VSB-2	10.04 ± 0.63	0.54 ± 0.24	3.31 ± 0.31	13.89 ± 0.07	ghi
Dvina	8.75 ± 0.06	0.74 ± 0.13	4.30 ± 0.02	13.80 ± 0.04	hij
Neva	10.03 ± 0.48	0.50 ± 0.09	3.24 ± 0.12	13.78 ± 0.50	hij
I-488	9.40 ± 0.44	0.64 ± 0.10	3.59 ± 0.24	13.64 ± 0.57	hij
ST-109	9.03 ± 0.05	0.46 ± 0.01	3.24 ± 0.48	12.73 ± 0.41	ijk
Categoría	8.35 ± 0.01	0.33 ± 0.02	3.65 ± 0.21	12.33 ± 0.19	jk
Chopa Blanca	8.47 ± 0.41	0.27 ± 0.07	3.03 ± 0.02	11.78 ± 0.31	k

Mean values followed by the same letters are not significantly different at $P < 0.05$.

Insoluble lignin values obtained in this study are closer to the range obtained by White [4] in hardwoods and softwoods, by Adam et al. [30] and Agblevor et al. [31] in hybrid poplars and similar to those presented by Fengel and Wegener [7] in wood of *P. tremuloides* and other poplars.

Soluble lignin has a low molecular weight. It is solubilized in an acidic hydrolysis solution and usually ranges between 0.5% and 4.0% of the dry mass. In this study, the values of soluble lignin showed little variability and were relatively high, ranging between 3.0% and 4.0%. This range is slightly higher than the one reported previously for poplar clones in short rotation schemes [1,28].

Table 4 – Klason lignin, soluble lignin and total lignin contents of *Populus* spp. clones as mass fraction (% on dry basis).

Clon	Klason lignin[a] (%)	Soluble lignin[a] (%)	Total lignin[a] (%)	
Constanzo	20.92 ± 1.14	3.91 ± 0.01	24.84 ± 1.14	a
Beaupre	20.61 ± 0.37	3.18 ± 0.01	23.80 ± 0.37	ab
Eridano	20.10 ± 0.74	3.44 ± 0.27	23.54 ± 0.47	abc
Carolinensis	19.81 ± 0.57	3.59 ± 0.02	23.40 ± 0.55	abcd
Categoría	18.40 ± 1.39	3.44 ± 0.08	21.84 ± 1.48	abcde
Nmdv	18.07 ± 0.12	3.54 ± 0.01	21.61 ± 0.14	abcde
Neva	17.35 ± 1.84	4.02 ± 0.09	21.37 ± 1.75	bcde
Bocalari	18.19 ± 0.13	2.98 ± 0.28	21.17 ± 0.41	bcde
I-488	17.39 ± 0.14	3.27 ± 0.02	20.66 ± 0.16	bcdef
NM6	17.23 ± 1.63	3.29 ± 0.11	20.52 ± 1.51	bcdef
ST-109	17.00 ± 1.12	3.35 ± 0.05	20.36 ± 1.07	cdef
VSB-2	16.59 ± 0.91	3.49 ± 0.20	20.08 ± 0.71	def
70038/31	16.70 ± 0.94	3.23 ± 0.14	19.93 ± 0.95	ef
Unal	16.37 ± 0.45	3.50 ± 0.14	19.88 ± 0.31	ef
269	16.29 ± 0.22	3.46 ± 0.08	19.75 ± 0.31	ef
Dvina	16.71 ± 0.26	2.98 ± 0.14	19.69 ± 0.12	ef
Chopa Blanca	16.42 ± 0.76	3.25 ± 0.04	19.67 ± 0.71	ef
Triplo	16.01 ± 0.17	3.28 ± 0.11	19.29 ± 0.06	ef
Boelare	14.31 ± 0.25	3.38 ± 0.02	17.69 ± 0.22	f

Mean values followed by the same letters are not significantly different at $P < 0.05$.

[a] Percentage based on material free of extractives.

Lignin content has a direct influence in the heating value of the biomass [4] because it is a high-energy component [32]. This fact was confirmed by the heating value determinations of the Klason lignin obtained in this study, which reached 22.89 MJkg^{-1}.

3.5. *Holocellulose*

Holocellulose content of the samples are shown in Table 5. Values ranged between 83.32% and 88.29%. These values are higher than the average of 77.2% reported by Vassilev et al. [33], the 79.12%–84.77% range obtained by Kacik et al. [6] and the 78.4%–80.3% range reported by Fengel and Wegener [7] in poplar wood. They are also higher than those obtained by Davis et al. [26] and Zamora et al. [34] from wood of hybrid clones of seven and thirteen years old respectively, in short rotation forestry systems established in Minnesota, USA. These higher values could be attributed to the presence of bark in the samples analyzed and a residual of lignin product of its incomplete oxidation or an incomplete extraction of polyphenols during the preparation of the wood free of extractives.

α-Cellulose ranged between 42.4% and 48.7%. Hemicellulose, obtained as a difference between holocellulose and cellulose, ranged between 38.81% and 42.48%. The reference value given by Vassilev et al. [33] for cellulose in hardwoods is 46.3%. In other studies with *Populus* spp. the values of cellulose ranged between 42.7% and 51%, while hemicellulose content is about 30% [1,6,9,34]. Results obtained in this study, although from juvenile wood with bark, are within the ranges reported previously.

3.6. *Ashes*

The ash content of the *Populus* spp. clones studied here ranged between 2.05% and 3.40% (Table 6). These values are higher

Table 5 – Holocellulose and α-Cellulose contents of *Populus* spp. clones as mass fraction (% on dry basis).

Clon	Holocellulose[a] (%)	Clon	α-Cellulose (%)
I-488	88.29 ± 0.61 a	*Beaupre*	48.70 ± 0.50 a
70038/31	88.29 ± 0.78 a	*NM6*	46.98 ± 0.22 ab
Boelare	88.22 ± 0.72 a	*Chopa Blanca*	46.96 ± 1.27 ab
Beaupre	88.09 ± 0.40 ab	*70038/31*	46.29 ± 0.28 abc
Carolinensis	87.82 ± 0.49 ab	*Boelare*	46.23 ± 0.57 abc
Chopa Blanca	87.65 ± 1.54 abc	*Unal*	46.19 ± 0.59 abc
Unal	87.53 ± 0.65 abcd	*Carolinensis*	46.10 ± 0.35 abc
ST-109	87.48 ± 0.11 abcd	*I-488*	45.81 ± 0.12 abc
Eridano	87.21 ± 0.24 abcde	*VSB-2*	45.52 ± 1.02 bc
Categoría	86.08 ± 2.32 abcdef	*Eridano*	45.51 ± 0.09 bc
NM6	85.96 ± 0.21 abcdef	*ST-109*	45.25 ± 0.38 bcd
Triplo	85.39 ± 1.14 abcdef	*Bocalari*	45.13 ± 0.61 bcd
VSB-2	85.13 ± 0.02 abcdef	*269*	44.89 ± 0.05 bcd
269	84.71 ± 0.64 bcdef	*Dvina*	44.77 ± 0.14 bcd
Bocalari	84.27 ± 0.51 cdef	*Categoría*	44.27 ± 2.08 bcd
Constanzo	84.09 ± 0.44 def	*Triplo*	44.09 ± 0.84 bcd
Neva	83.77 ± 0.89 ef	*Nmdv*	43.85 ± 0.31 cd
Dvina	83.58 ± 0.27 f	*Constanzo*	42.48 ± 0.06 d
Nmdv	83.32 ± 0.68 f	*Neva*	42.38 ± 0.80 d

Mean values followed by the same letters are not significantly different at $P < 0.05$.

[a] Percentage based on material free of extractives.

than the 0.45% reported by Scurlock [29] as typical for hardwoods, the 0.2%–0.4% range reported for poplar wood [31] and the 0.5%–0.9% range reported for *Populus* spp. in short rotations [31]. The explanation for our results could be that the young bark or phloem has higher ash content than wood [35]. Although higher than the values reported previously, the ash content on samples including bark does not impose any limitation as a feedstock for combustion, pyrolysis and gasification. However, additional characterization of the composition of these ashes would be necessary in order to identify potential contaminants in the process of energy production [33] and technical troubles such as slagging, fouling, sintering and corrosion in the combustion system [36]. Caution must be given in using HHV as the only criterion of quality for clone selection, because there are other factors that have to be considered when choosing clones for energy purposes, such as ash composition, S and Cl content and agglomeration tendency [37–41]. Such characterization is beyond the scope of this study.

Table 6 – Ash content of poplar clones as mass fraction (% on dry basis).

Clon	Ash (%)	Clon	Ash (%)
Carolinensis	3.40 ± 0.23 a	*Boelare*	2.69 ± 0.03 abcde
NM6	3.38 ± 0.16 ab	*Unal*	2.60 ± 0.13 abcde
I-488	3.27 ± 0.05 abc	*Chopa Blanca*	2.58 ± 0.45 bcde
70038/31	3.24 ± 0.08 abcd	*Triplo*	2.47 ± 0.04 cde
VSB-2	3.11 ± 0.31 abcd	*Dvina*	2.44 ± 0.12 de
Beaupre	2.83 ± 0.17 abcde	*269*	2.22 ± 0.04 e
Bocalari	2.77 ± 0.38 abcde	*Categoría*	2.10 ± 0.14 e
ST-109	2.75 ± 0.01 abcde	*Neva*	2.09 ± 0.23 e
Nmdv	2.73 ± 0.07 abcde	*Constanzo*	2.05 ± 0.14 e
Eridano	2.71 ± 0.01 abcde		

Mean values followed by the same letters are not significantly different at $P < 0.05$.

Ash Percentage based on material free of extractives.

3.7. *Correlations between the chemical composition and extractives content on HHV*

We look for correlations between the chemical composition and extractives on HHV (not shown here), and found very low square correlation coefficient values ($R^2 < 20$). Among all the correlation models proposed in the literature [5,42–44], the most suited for our data was the one proposed by Demirbas [5], although the square correlation coefficient value was also low. Thus, our results show a lack of correlation between the chemical composition and extractives on HHV, as suggested by Sheng and Azevedo [45]. We attributed this lack of correlation to the variable chemical structure and composition of the clones' biomass, the use of juvenile wood and the presence of bark in the samples analyzed.

3.8. *Energy production*

We used the biomass yield and its energy content (HHV) to establish a ranking of the energy potential of the clones studied (Fig. 2). Clone Bocalari showed the highest yield and one of the highest HHV, so was the clone with the highest energy potential (486 GJ ha^{-1} $year^{-1}$) and the best candidate for energy generation by combustion. Beaupre and Constanzo were in the second and third place with 273 and 263 GJ ha^{-1} $year^{-1}$ respectively. Constanzo, although with the lowest HHV could compensate its energy potential due its high biomass productivity. On the other hand, clone VSB-2 although with a high HHV, it occupied the lowest position in the ranking due its low biomass yield.

In general, the position on the energy potential ranking is related to the biomass productivity. However, for clones with similar yield (Constanzo and Beaupre) the position in the ranking depends strongly on the HHV. Thus, biomass productivity is the most important factor when selecting clones for energy purposes, but for clones with similar productivity, HHV should also be used as a selection criterion.

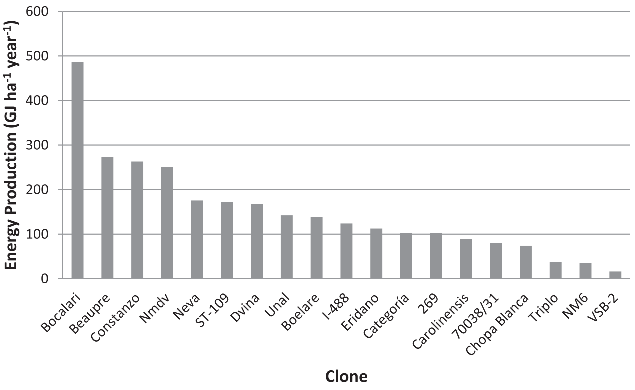

Fig. 2 – Ranking of the *Populus* spp. clones studied by their energy potential as a combination of biomass yield and HHV.

The energy production values of this study confirmed the results presented by Luo and Polle [23], who obtained energy productions that ranged between 368.5 and 461.5 GJ ha^{-1} $year^{-1}$ in *Populus* clones of similar age (two years old) and growing conditions (irrigated and unfertilized) to those of this study.

4. Conclusions

Data presented here confirm the potential of using *Populus* for biomass production purposes in the Mediterranean Zone of Chile. Yields obtained in this study are alike to those reported worldwide with different *Populus* clones and similar management.

The use of bark and juvenile wood in the samples analyzed in this work modify substantially the extractives and lignin contents of the biomass when compared with previous studies on chemical quality of mature wood on the same species. The ash content reported, higher than the average for the *Populus* genre, is attributed to the presence of bark in the raw material. However, the ash content on samples including bark does not impose any limitation for using this type of biomass in thermochemical processes.

As previously reported in the literature, our results show a lack of correlation between the chemical composition and extractives on HHV.

When defining the energy potential of a poplar clone for direct combustion purposes, a combination of biomass yield and quality must to be considered. In our study, Bocalari, Beaupre, Constanzo and Nmdv growing under irrigation at a density of 5000 plants ha^{-1} demonstrated been the most promissory clones for biomass production in the Mediterranean Zone of Chile.

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