Bioresource Technology 100 (2009) 440–445

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Integral valorization of two legumes by autohydrolysis and organosolv delignification

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ARTICLE INFO

Article history:
Received 14 February 2008
Received in revised form 30 April 2008
Accepted 1 May 2008
Available online 9 August 2008

Keywords:
Leucaena
Chamaecytisus
Autohydrolysis
Pulp
Organosolv

ABSTRACT

Two woody legumes species (*Chamaecytisus proliferus* L.F. ssp. palmensis and *Leucaena diversifolia*) were evaluated for integrally exploitation. The raw material was subjected to autohydrolysis under variable operating conditions which provided a liquid phase rich in hemicellulose oligomers and a solid phase that was used to obtain cellulose pulp and paper sheets by using organosolv procedures. The chemical properties of both *C. proliferus* and *L. diversifolia* allow their integral exploitation by using a hydrothermal treatment prior to their organosolv pulping with ethanol. The pulp yields obtained are quite high (40.3% for *L. diversifolia* and 58.2% for *C. proliferus*), and so are the sugar concentrations in the liquors from the thermal pretreatment (viz. 16.1 and 20.0 g oligomers/l in *C. proliferus* and *L. diversifolia*, respectively, and 1.5 and 1.1 g xylose/l, respectively, in the two raw materials). The strength-related properties of the paper sheets obtained are acceptable (tensile index 7.76 and 10.77 kN m/kg for *C. proliferus* and *L. diversifolia*, respectively and kappa index 31 and 12.5 for *C. proliferus* and *L. diversifolia*, respectively), but somewhat worse than those provided by other raw materials such as eucalyptus; however, they can be improved by mechanical refining of the pulp.

1. Introduction

The world is experiencing a growing shortage of raw materials which is especially severe in the energy sector and being worsened by the unfavourable environmental impact of a consumerist culture revolving around the exploitation of non-renewable resources. Accomplishing sustainable development and renewability entails finding and using new resources and chemical and consumer products where lignocellulosic biomass constitutes a "necessary" source of raw materials on account of its ubiquity, availability and low polluting power. In fact, lignocellulosic biomass has been widely acknowledged as the largest source of renewable energy available in the world to respond to the decline in fossil fuel sources (Ozcimen and Karaosmanoglu, 2004; Jefferson, 2006; Semelsberger et al., 2007). Processing the whole material rather than only its sugar and amylaceous fractions to obtain ethanol by fermentation, its fibre fractions to produce cellulose pulp and some residual fractions or all for burning is the only way of exploiting the whole potential of such an abundant resource (Kim and Dale, 2004).

The alternative to integral exploitation of lignocellulosic biomass in a single process (usually of the thermal type) inevitably involves its fractionation; this is hindered by the inability to separate its main components without degrading the chemical structure of some. Extensive research in this field has focussed on a variety of highly specific issues and hindered systematic, comprehensive compilation of available fractionation methods. In dealing with such methods, Rijkens (1984) discriminates between those based on delignification (i.e. the solubilization of lignin) and those relying on hydrolysis (i.e. the solubilization of polysaccharides). This was the origin of the "lignocellulosic material biorefinery" concept as the source of a wide range of products by analogy with the "oil refinery" concept. Although a number of refining schemes have been tested at the laboratory or pilot plant scale, none has to date been implemented on a commercial scale (Kamm and Kamm, 2004; Lynd et al., 1999).

Using biomass from forest or agrarian "crops" to extract energy or chemical products provides environmental advantages. Also, using resprouting plants and harvesting their aerial portion only – thus leaving roots and shoots intact – reduces the need for machine tillage – and hence energy use – for as long as the plants retain their regrowing ability. Thus, soil degradation has been described as an important problem in Europe: 12% of total European land area has been affected by water erosion and 4% by wind erosion (Ananda and Herat, 2003). Leguminous species helping to the recovery of already degraded grounds because biological nitrogen fixing that happens while symbiosis between bacteria and plants is the main way of having nitrogen in the biosphere. Woody legumes can prevent erosion, increase soil fertility and facilitate

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0960-8524/$ - see front matter © 2008 Published by Elsevier Ltd.
doi:10.1016/j.biortech.2008.05.003

the establishment and growth of other plant species (Cross and Schlesinger, 1999; Rodríguez-Echevarría et al., 2003).

Under this perspective, the use of *Chamaecytisus proliferus* and *Leucaena diversifolia* in soil restoration has been studied in several countries (Vanlauwe et al., 1998; Sharma et al., 1998; Santana et al., 2003), like protection to face the wind and erosion control (Wills et al., 1998), to improve salinity soils (Eastham et al., 19933), to increase the fertility of the soil by nitrogen fixation or contribution of nutrients (McKenzie et al., 2001; Unkovich et al., 2000) and to grow on poor soils (Rout et al., 1999; Ma et al., 2003).

In addition, lignocellulosic materials can be used to extract fermentable substrates from oligosaccharides, xilooligosaccharides, chemical product such as lignin of furfural, paper and pulp, compost or even energy.

Lignocellulosic raw materials are abundant and renewable. In fact, an estimated 10–50 billion ton dry matter of this type is produced each year in the world (Claassen et al., 1999; Galbe and Zacchi, 2002).

Two woody legumes species (*C. proliferus* L.F. ssp. *palmensis* and *L. diversifolia*) were evaluated for integrally exploitation. The raw material was subjected to autohydrolysis under variable operating conditions which provided a liquid phase rich in hemicellulose oligomers and a solid phase that was used to obtain cellulose pulp and paper sheets by using organosolv procedures.

2. Experimental

2.1. Raw material

The raw material used, which was prepared in accordance with TAPPI T-257, was analysed for the following parameters: 1% NaOH solubles (TAPPI T-212), ethanol–benzene extractives (TAPPI T-204), holocellulose (Wise et al., 1946) and ash (TAPPI T-211). In addition, the cellulose and hemicellulose composition of the material, in the form of glucan, xylan, araban and acetyl groups, was determined by high performance liquid chromatography (HPLC). To this end, portions of the homogenized wood lot were subjected to quantitative acid hydrolysis with 72% sulphuric acid (TAPPIT-249-em-85). The solid residue after hydrolysis was recovered by filtration and considered as Klason lignin. The monosaccharides and acetic acid contained in hydrolysates were determined by HPLC in order to estimate (after corrections for stoichiometry and sugar decomposition) the contents of samples in cellulose (as glucan), hemicelluloses (xylan), and acetyl groups.

2.2. Hydrothermal treatment

C. proliferus and *L. diversifolia* wood trimmings samples were milled to pass a 8 mm screen, since no diffusional limitations were observed for this particle sice in preliminary studies.

The hydrothermal treatment involved non-isothermal hydrolysis in a Biometa high-pressure batch reactor furnished with a heating body. Treatments were done by using the highest heating rate; once the desired temperature level was reached, heating was stopped and the reactor cooled by circulating cold water through an internal coil in order to obtain results similar to those of isothermal processes but in a shorter time. *C. proliferus* was heated at 185 °C and *L. diversifolia* at 195 °C. These temperatures were intended to provide a high proportion of hemicellulose oligomers in the residual liquors of the pretreatment without damaging cellulose fibres in the material in order to avoid excessively diminishing the strength of the resulting paper sheets. Sheets from untreated *L. diversifolia* were found to be stronger than sheets from untreated *C. proliferus*. This allowed a temperature 10 °C higher to be adopted for the latter. Also, the oligomer concentrations in the liquors were found to grow faster at high temperatures in *C. proliferus* than in *L. diversifolia*. Therefore, specific sugar levels in the liquor can be obtained by using lower pretreatment temperatures with *C. proliferus* than with *L. diversifolia*.

The solid/liquid ratio was fixed at 1/6.5 oven-dry raw material/kg water, which is the lowest level found to ensure homogeneous mixing in practice.

After treatment, solid residues were recovered by filtration and washed with water and liquor was filtered through membranes of 0.45 μm pore size and used for direct HPLC determination of oligosaccharides, monosaccharides (glucose, xylose and arabinose), furfural, 5-hydroxymethylfurfural (HMF) and acetic acid.

2.3. Pulp and papermaking procedures

Cellulose pulp was obtained in the same reactor used in the hydrothermal pretreatment.

The operating conditions for *Chamecytisus proliferus* were the optimum conditions found in previous work (Díaz et al., 2004; López et al., 2004): 175 °C, 60%-v ethanol, 90 min: solid/liquid ratio: 1/10; Those for *L. diversifolia* were as follows: 185 °C, 30%-v ethanol, 21%-w sodium hydroxide, 0.5%-w anthraquinone; 60 min; solid/liquid ratio: 1/8 (on a dry weight basis) (López et al., 2008; Díaz et al., 2007).

Following cooking, the pulp was separated from the liquor and disintegrated, without damaging the fibers, during 3 min (2500 rpm), washed on a sieve of 0.16 mm mesh, defibered and passed through a Strainer filter (0.4 mm mesh) in order to isolate the uncooked material.

Pulp was prepared for paper making in accordance with UNE 57-026 and sheets were obtained by using an ENJO F-39 sheet former according to UNE 57-042-91.

Pulp characterization experiments involved the following parameters: pulp yield (TAPPI T-257), kappa number (TAPPI T-236), viscosity (UNE 57-025), and the following strength-related parameters: tensile index (UNE 57-055-79 and UNE 57-028), Burst index (UNE 57-055-79 and UNE 57-058) and tear index (UNE 57-055-79 and UNE 57-033).

3. Results and discussion

3.1. Chemical properties of the raw materials

Table 1 shows the chemical composition of various raw materials used to produce cellulose pulp including those employed in this work. Eucalyptus (*Eucaliptus globulus*) was used as reference by virtue of its being among the most widely used species for cellulose pulp and paper making.

Except for wheat straw, (Pan and Sano, 2005) all raw materials contain less glucan than eucalyptus (Garrote et al, 2003), (from 15.6% less in *Miscantus sinensis* (Ververis et al, 2004) to 27.8% in sunflower stalks), (Caparrós et al, 2006). *C. proliferus* and *L. diversifolia* have quite similar glucan contents (38.9% and 39.5%, respectively, which are 16.9% and 18.9% lower, respectively, than that of eucalyptus).

Hydrothermal treatments help solubilize extracts and facilitate access to raw materials by delignification reagents. Grass species contain increased proportions of ethanol–benzene extractives (especially *Arundo donax*, with 9.1%); by contrast, *C. proliferus* contains 2.3% and *L. diversifolia* 1.7% (vs. 1.2% in eucalyptus). *C. proliferus* has a lower lignin content than have *L. diversifolia* and eucalyptus. Although the susceptibility to delignification depends on the content and structural characteristics of lignin (syringyl and guayacyl units), it should be easier to delignify than these two species. In fact, the lignin contents of *C. proliferus* and *L. diver-*

Table 1
Chemical composition of *Chamaecytisus proliferus* and other lignocellulosic materials*

	Chamaecytisus proliferus	*Leucaena diversifolia*	*Eucalyptus*[a]	Wheat straw[b]	*Miscanthus sinensis*[c]	*Arundo donax*[d]
NaOH 1% solubles	21.2	15.9	12.4	–	–	–
Ethanol extractives (%)	2.3	1.7	1.2	5.3	4.2	9.1
Ash (%)	0.7		0.6	9.6	2.0	3.0
Glucan (%)	38.9	38.0	46.8	55.4	39.5	34.8
Klason lignin (%)	19.8	24.8	22.9			23.0
Holocellulose (%)	80.3	65.8	66.9	76.2	69.4	64.5
Xilan (%)	19.9	15.7	16.6	34.6	19.0	19.4
Araban (%)	0.6	1.5	0.5	5.6	1.8	1.5
Acetyl groups (%)	4.4	3.3	3.5	–	–	3.4
Others (%)	12.5		10.1	–	–	–

* Percentages relative to raw material (100 kg dry matter).
[a] Garrote et al. (2003).
[b] Pan and Sano (2005).
[c] Ververis et al. (2004).
[d] Caparros et al. (2006).

sifolia are 13.5% lower and 8.3% higher, respectively than that of eucalyptus.

Worth special note is the increased hemicellulose content of *C. proliferus* (41.4%, calculated as the difference between the holocellulose and glucan contents) relative to all other materials including eucalyptus (20.1%). This difference could be ascribed to other hemicellulosic compounds or 1% NaOH solubles substances. *C. proliferus* with bark has been used in this study, but López et al. (2004) reported that the bark chemical characterization show high 1% NaOH solubles (63.4%). The hemicellulose content of *L. diversifolia*, 27.8%, is similar to those of *Miscantus sinensis* and *Arundo donax*.

Specially important among hemicellulose heteropolymers is xylan, which is especially abundant in wheat straw (34.6%). The xylan contents of *C. proliferus* and *L. diversifolia* are 19.9% higher and 5.7% lower, respectively, than that of eucalyptus.

As regards pentoses, araban is present in similar proportions in *C. proliferus* and eucalyptus (0.63% and 0.54%, respectively), but in substantially higher levels in *L. diversifolia* (1.46%).

Hydrothermal treatments cause the dissolution of hemicellulose polysaccharides. The effect is strengthened by the release of acetyl groups from hemicelluloses raising the acidity of the medium (Önnerud and Gellerstedt, 2003). The contents in acetyl groups of *C. proliferus* and *L. diversifolia* are 25.8% higher and 5.44% lower, respectively, than that of eucalyptus.

3.2. Hydrothermal treatment

As can be seen from Table 2, using low temperatures (165–175 °C) in the hydrothermal treatment resulted in the presence of increased amounts of oligomers in the liquors from *L. diversifolia* (4.18–8.29 g/l) relative to *Chamaecitysus proliferus* (3.3–5.7 g/l). The opposite effect, however, was observed at high temperatures; thus, the tagasaste liquors obtained at 185–195 °C contained oligomer concentrations of 16.1–23.4 g/l vs. 15.37–20.02 g/L for *L. diversifolia*. One should bear in mind that *C. proliferus* contains a 48.6% higher proportion of hemicelluloses, which this suggest that *L. diversifolia* can be readily attacked at low temperatures. This is consistent with the amounts of polymer in the raw material converted into sugars in the process, which was 1.5–2.6 times greater for *L. diversifolia* than for *C. proliferus* over the studied temperature range (see Table 3).

The greatest increase in oligomer concentration in solution for *C. proliferus* occurred from 175 to 185 °C, where it grew nearly three times. *L. diversifolia* exhibited no comparable variation and exhibited the greatest changes over the temperature range 165–185 °C.

The autohydrolysis of eucalyptus at 181 °C (Garrote and Parajó, 2002) converts 8.7% of the raw material into dissolved oligomers (Table 4); such a proportion falls within the ranges for *C. proliferus* (3.3–9.4%) and *L. diversifolia* (6.63–12.3%) at temperatures from 175 to 185 °C.

The oligosaccharide and xylose contents of the liquors from a hydrothermal treatment are important with a view to their exploitation. The amount of xylose in *C. proliferus* liquors is 2.2–3 times greater than that in *L. diversifolia* liquors. The polymer (xylan) fraction providing the sugars is at most 3.2–8.3% in *C. proliferus* and 1.7–5.03% in *L. diversifolia*.

The amount of polymer that is dissolved at temperatures of 175–185 °C in *C. proliferus* is strongly temperature-dependent, whereas that of xylan is not. Thus, raising the temperature from 175 to 185 °C causes only 21.2% of the original polymer in *C. proliferus* to be dissolved; by contrast, roughly 60% of xylan in *L. diversifolia* is degraded to xylose from 175 to 185 °C.

Table 2
Concentrations of sugars and various other substances in the liquors from the hydrothermal treatment

	Concentration (g/L)							
	Chamaecytisus proliferus				*Leucaena diversifolia*			
Hydrothermal temperatures (°C)	165	175	185	195	165	175	185	195
Oligomers[a]	3.3	5.7	16.1	23.4	4.2	8.3	15.4	20.0
Glucose	1.5	1.9	1.8	2.1	2.4	2.4	2.4	2.4
Xylose	1.1	1.3	1.5	2.8	0.4	0.4	0.7	1.1
Arabinose	0.2	0.4	0.7	1.0	–	0.2	0.3	0.4
Acetic acid	0.4	0.5	0.8	1.7	0.3	0.4	0.6	1.1
HMF[b]	0.0	0.0	0.0	0.1				
Furfural	0.0	0.0	0.0	0.2				

[a] Expressed as xylose equivalents.
[b] HMF: Hidroximethilfurfural.

Table 3
Oligomer and monomer concentration of the hydrothermal treatment liquors relative to those in each polymer fraction in the dry raw material

	Percentage (%)							
	Chamaecytisus proliferus				*Leucaena diversifolia*			
Hydrothermal temperatures (°C)	165	175	185	195	165	175	185	195
Oligomers[a]	9.6	16.6	47.4	69.8	21.3	42.3	78.5	102.3
Glucose	2.3	2.8	2.7	3.2	4.5	4.5	4.5	4.5
Xylose	3.2	3.7	4.5	8.3	1.7	2.0	3.1	5.0
Arabinose	23.0	32.9	62.6	97.3		7.3	13.6	17.5
Acetic acid	3.9	5.0	8.7	18.9	6.5	8.2	13.6	23.0
HMF	0.0	0.0	0.1	0.2				
Furfural	0.0	0.1	0.1	0.8				

[a] Expressed as xylose equivalents.

Table 4
Oligomer and monomer contents in the liquid phase relative to dry raw material as compared with those of eucalyptus

	Percentage (%)								
	Chamaecytisus proliferus				Eucalyptus[a]	*Leucaena diversifolia*			
Hydrothermal temperature (°C)	165	175	185	195	181	165	175	185	195
Oligomers	1.9	3.3	9.4	13.9	8.7	3.3	6.6	12.3	16.0
Glucose	0.9	1.1	1.1	1.2	0.2	1.9	1.9	1.9	1.9
Xylose	0.6	0.7	0.9	1.7	1.0	0.3	0.3	0.5	0.9
Arabinose	0.1	0.2	0.4	0.6	–		0.1	0.2	0.3
Acetic acid	0.2	0.2	0.4	0.8	0.2	0.2	0.3	0.5	0.9
HMF	0.0	0.0	0.0	0.1	–				
Furfural	0.0	0.0	0.0	0.1	0.1				

*These results are from Garrote et al., 2003. The temperature and liquid/solid ratio are 181 °C and 6/1 respectively. The liquid/ratio for chamaecytisus and leucaena is 6.5/1 (Section 2.2 Hydrothermal treatment).
[a] Garrote et al. 2003.

Hydrothermal treatment at 181 °C converts 1% of eucalyptus material into xylose in the liquor (Table 4); this fraction is 11.1–42.9% greater than that for *C. proliferus* and 194.1–85.19% greater than that for *L. diversifolia*, both over the temperature range 175–185 °C.

Although the amount of sugars in solution should be as high as possible, degradation of cellulose (as glucan) in the raw material should be avoided as far as possible in order to obtain pulp of acceptable properties. While the glucan contents of *C. proliferus* and *L. diversifolia* are very similar, the fraction of polymer degraded by the hydrothermal treatment is much higher in *L. diversifolia* than in *C. proliferus* at any temperature, as confirmed by the increased glucose content of the liquors from *L. diversifolia* (2.38–2.43 g/l) relative to *C. proliferus* (1.5–2.1 g/l), although glucose partly generated from hemicellulosic polymers could be partially explain the difference. Also, degradation starts at lower temperatures in *L. diversifolia*: at 165 °C, the glucose content of the liquors is 62% higher than in the *Chamacytisus proliferus* liquors; above that temperature, the difference ranges from 13.3% at 195 °C to 35% at 185 °C. The fraction of glucan dissolved by the hydrothermal treatment is virtually twice as high in *L. diversifolia* than in *C. proliferus* (Table 3).

The cellulose in eucalyptus is less readily attacked by cooking in water; in fact, only 0.2% of raw material is converted into glucose at 181 °C, vs. 1.1% in *C. proliferus* and 1.94% in *L. diversifolia* (Table 4); these data suggest that the cellulose in *L. diversifolia* is the most easily degraded by a hydrothermal treatment.

At 195 °C, all araban present in *Chamaecitysus proliferus* is converted into sugars (arabinose); however, because the proportion of araban in the raw material is very low (0.63%), the maximum concentration of arabinose in the liquor is only 1 g/l, which is 2.7 times lower than that for *L. diversifolia*.

Acetyl groups in *L. diversifolia* are more easily released than those in *C. proliferus* judging from the proportions of polymer that are dissolved in the two (6.5–21.01% vs. 3.9–18.9%). However, the concentration of acetic acid in the liquors is higher for *C. proliferus* (0.4–1.7 g/l) than for *L. diversifolia* (0.3–1.07 g/l), which is consistent with the fact that the content in acetyl groups of *C. proliferus* is 33% higher.

Table 5
Comparison of the results obtained in the organosolv pulping of *Chamaecytisus proliferus* and *Leucaena diversifolia* subjected to hydrothermal treatment and no pretreatment with those for eucalyptus pulp

	Chamaecytisus proliferus		*Leucaena diversifolia*		Eucalyptus (Garrote, 2003)
	With hydrothermal pretreatment	Without hydrothermal pretreatment	With hydrothermal pretreatment	Without hydrothermal pretreatment	With hydrothermal pretreatment
Hydrothermal treatment temperature (°C)	185		195		181
Yield (%)	58.2	42.6	40.3	39.7	69.6
Kappa number	31.0	66.0	12.5	16.1	75.5
Viscosity (ml/g)	770	1056	303	486	702
Tensile index (kN m/kg)	4.45	7.76	3.72	10.77	22.6
Burst index (MPa m^2/kg)	0.06	0.28	0.28	0.32	0.68
Tear index (N m^2/kg)	4.10	4.54	1.60	1.97	5.70

3.3. Properties of the pulp and paper sheets

The pulp yields obtained following autohydrolysis (Table 5) were quite high (58.2% for *C. proliferus* and 40.3% for *L. diversifolia*) if one considers that they were the result of two reactions. Such yields are 16.4% and 42.1%, respectively, lower than those previously obtained for eucalyptus under similar conditions (Garrote et al., 2003).

Interestingly, the overall yield of the autohydrolysis ethanol pulping process exceeds that obtained with ethanol cooking alone. This is especially so with *C. proliferus*, where the pulp yield obtained with the hydrothermal treatment is 58.2%, whereas that obtained with no pretreatment is only 42.6%. The respective yields for *L. diversifolia* are 40.3% and 39.7%, respectively. This may be the result of the hydrothermal treatment dissolving hemicelluloses acting as binders between lignin and cellulose, and the material being more readily accessible by the reagents as a result; as a consequence, the amount of uncooked material is smaller and the yield higher. Similar results in this respect were previously obtained by other authors; while an increased dissolution of hemicelluloses and lignin should decrease pulp yield, a hydrolysis pretreatment occasionally reduces cellulose losses, with little effect on pulp yield.

L. diversifolia exhibits the smallest kappa number by effect of the presence of soda in its cooking liquors and the high temperature of its hydrothermal treatment. The kappa numbers for the studied materials are smaller than those for eucalyptus, possibly as a result of differences in the way the pulp was washed after cooking. The relatively low values for kappa number could be involved with high contents in cellulose. Moreover, the disintegrated/wash procedure has been adequate for preventing the recondensation and precipitation of lignin.

Hydrothermally treated *C. proliferus* provides pulp of similar viscosity to that of eucalyptus pulp (Garrote et al., 2003).

Table 5 shows the strength-related properties of paper sheets from *C. proliferus* and *L. diversifolia* pulp obtained by ethanol cooking with and without a hydrothermal pretreatment. As expected, the pretreatment decreases the strength of the resulting properties.

The strength of the paper sheets obtained with no pretreatment is higher in *L. diversifolia* than in *C. proliferus*; by exception, the tear index is higher in *C. proliferus* (4.54 vs. 1.97 N m^2/g). The tensile index and burst index of the *L. diversifolia* sheets are 38.8% and 14.3% higher, respectively, than those of the *C. proliferus* sheets. The pretreatment diminishes the strength of the paper sheets more markedly in *L. diversifolia* than in *C. proliferus* – by exception, the burst index is reduced four times more in the latter. The tensile index of the *C. proliferus* and *L. diversifolia* sheets is 1.7 and 2.9 times higher, respectively, with pretreatment. The difference in tear index between including and excluding the hydrothermal pretreatment in the process is less marked, however: 4.1 *vs* 4.54 N m^2/kg in *C. proliferus*, and 1.60 vs. 1.97 N m^2/kg in *L. diversifolia*.

4. Conclusions

The chemical properties of both *C. proliferus* and *L. diversifolia* allow their integral exploitation by using a hydrothermal treatment prior to their organosolv pulping with ethanol.

The pulp yields obtained are quite high (40.3% for *L. diversifolia* and 58.2% for *C. proliferus*), and so are the sugar concentrations in the liquors from the thermal pretreatment (*viz.* 16.1 and 20.0 g oligomers/l in *C. proliferus* and *L. diversifolia*, respectively, and 1.5 and 1.1 g xylose/l, respectively, in the two raw materials).

The strength-related properties of the paper sheets obtained are acceptable, but some what worse than those provided by other raw materials such as eucalyptus; however, they can be improved by mechanical refining of the pulp.

The hydrothermal treatment of *C. proliferus* at lower temperatures (185 vs. 195 °C for *L. diversifolia*) results in increased pulp yields and in stronger paper sheets. Also, its increased content in hemicelluloses makes it more suitable for the intended use. In addition, cellulose is less markedly degraded in *C. proliferus* than in *L. diversifolia* at the temperatures of the hydrothermal treatment studied.

Acknowledgements

The authors acknowledge financial support from the ENCE, S.A. (San Juan del Puerto factory. Huelva, Spain) and the CICYT-FEDER (Science and Technology Inter Ministerial Commission, Spanish Government – European Regional Development Fund), project number CTQ2006-10329/PPQ and to the Ramón y Cajal programme (Spain's Ministry of Education and Science) for additional funding.

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