Eucalyptus globulus Stumpwood as a Raw Material for Pulping

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In this study, *Eucalyptus globulus* stumpwood samples collected from six different sites in Portugal were evaluated for their ease of pulping, using two delignification processes (kraft and alkaline sulfite-anthraquinone-methanol (ASAM)). Morphologically, the stumpwood included fibers with a mean length of 0.930 mm, diameter of 21.4 µm, lumen width of 9.1 µm, and cell-wall thickness of 6.1 µm. The Runkel ratio varied between 1.0 and 1.9, and the slenderness ratio ranged between 50.6 and 35.1. ASAM pulps presented higher yields and kappa numbers (49.3% and 36, respectively) when compared to kraft pulps (42.7% and 14, respectively). Extractive-free material increased pulp yield (51.7% and 47.5% for ASAM and kraft, respectively) and decreased kappa number (18 and 11). The kraft pulps showed a coarseness of 0.096 mg/m, curl of 5.2%, and 16.7% kinked fibers, while for the ASAM pulps, these values were 0.105 mg/m, 5.2%, and 16.3%, respectively.

Keywords: Eucalyptus globulus; Stumpwood; Fiber chemistry and morphology; Pulping; Kraft; ASAM

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INTRODUCTION

Eucalyptus globulus Labill. (Tasmanian blue gum) is a highly valued raw material for pulp and paper manufacturing due to fast growth. It is also associated with an excellent wood quality for production of bleached pulp for printing papers (Pereira *et al.* 2011). Portugal and Spain are the main countries with commercial *E. globulus* plantations (Potts *et al.* 2004). In Portugal, it is the most planted species, with 812 million ha (ICNF 2013), and in Spain, its area is reported at 760 million ha (MAAMA 2013).

Industrial pulpwood plantations of *E. globulus* are managed in a short-rotation coppice system, with 8- to 14-year rotations, depending on the edaphoclimatic conditions. The stands are normally exploited with three cutting cycles, and at the end of the commercial exploitation, the plantations must be re-established and the stumps removed prior to soil preparation (Barreiro and Tomé 2012; Soares and Tomé 2012).

The stump is the basal part of the tree, including the near-the-ground stem portion and the woody roots, which remain after stem felling (Forest Research 2009). It is the oldest part of the tree, therefore enriched in heartwood (Gominho and Pereira 2005), reaction wood, and cicatricial tissues, in addition to higher levels of extractives and polysaccharides (Rowell 2005).

For *E. globulus*, the volume of the below-ground biomass is significant (40 to 60 tonnes ha^{-1}) and its mass is about 25% that of the above-ground standing biomass (stem, bark, branches, and leaves) (Soares and Tomé 2004). For spruce, the mass of stumps and roots represent 25 to 30% of the dry mass of trunks (Hakkila and Aarniala 2004).

In a previous study, Gominho *et al.* (2012) characterized eucalypt stumps in terms of basic density, ranging between 0.55 g cm^{-3} and 0.71 g cm^{-3}, and chemical composition. Stumpwood has a holocellulose content similar to commercial stemwood, but the high extractives content (15.1%), mostly ethanol-soluble compounds (10.5%), can cause problems during the pulping and bleaching operations of pulp manufacture.

Currently, eucalypt stumps are used as biomass for combined power and heat (CPH) generation (Gominho *et al.* 2012; Kärhä 2012). However, stumpwood can be envisaged as a raw material for pulping, thereby enlarging the eucalypt fiber feedstock, assuming that a convenient cleaning process is found to remove the contaminating soil particles that are usually present in this type of biomass. The removal of stumps from the field also must be carefully considered because of the potential negative ecological impacts that may affect the site's fertility, stand biological sustainability, regeneration, and survival of understory native species (Bauhus *et al.* 2001).

In the 1970s and 1980s, several experiments were done using stumpwood as the raw material for pulp and energy; however, additional experimentation was discontinued due to the high costs of harvesting and cleaning of this raw material (Kärhä 2012). In general, pulps made with stumpwood afforded lower yields and brightness and higher kappa numbers when compared with those of stemwood (Hatton and Keays 1972; Peckham and McKee 1975).

Other forest residues can be used as raw materials for pulp production. Miranda *et al.* (2012) studied the incorporation of *E. globulus* barks and tops in the wood pulping feedstock. Different delignification processes were studied for various lignocellulosic residues: kraft pulps from stumps and roots of Douglas-fir (*Pseudotsuga menziesii*) (Hatton and Keays 1972); organosolv pulping (Mutjé *et al.* 2005), as well as kraft pulping (Requejo *et al.* 2012), of olive trees prunings (*Olea europea*); kraft pulping of balsam fir (*Abies balsamea*) thinnings (Hussein *et al.* 2006); and soda-anthraquinone, kraft, and organosolv pulping of holm oak (*Quercus ilex*) trimmings (Alaejos *et al.* 2006).

The objective of this study was to investigate the delignification ease of *E. globulus* stumps as a fiber feedstock for pulping with respect to its use in papermaking. Delignification of different samples of stumpwood was performed with kraft and alkaline sulfite-anthraquinone-methanol (ASAM) processes and evaluated by determinations of pulp yield, kappa number, viscosity, and color parameters. The effect on pulping of a pre-extraction of the stumpwood for removal of extractives was also investigated. The study included the determination of fiber biometry and morphological parameters in the stumpwood raw material, as well as the biomorphology of the pulp fibers. As an approximation to the potential of the commercial availability of stump biomass, field samplings with different characteristics were made in six locations in Portugal.

EXPERIMENTAL

Materials

The stumps of *Eucalyptus globulus* Labill. used in this study were collected in six stands in Portugal, including four commercial plantations for pulpwood production under re-establishment ([HF] - Herdade dos Fidalgos; [SO] - Serra da Ossa; [T] - Taipadas; and

[F] - Farrestelo), and two stands under conversion to other uses ([L] - Loure; and [VA] - Vale Andorinho). The stumpwood age was 38, 40, 42, and 24 years, respectively, for [HF], [SO], [T], and [F]. The [L] and [VA] sites presented more than 35 years old. The stand characteristics and the mechanical extraction methods for stump removal have been described by Gominho *et al.* (2012).

The samples were taken from the crushed stump pile in each site by combining subsamples taken from different individual stumps. The stumps included the rootwood and the above ground stem portion of the tree. The samples were cleaned to remove bark, further brushed to remove sands and soil, cut in small pieces, and oven dried at 60 ºC until a constant mass was reached. The purpose of the drying was to establish a repeatable starting point for the analysis.

The samples were chipped in a Retsch SM 200 knife mill (Retsch; Düsseldorf, Germany) with an output sieve of 10 mm x 10 mm and screened using a vibratory apparatus (Retsch AS 200 basic) with a 10-mesh (2.0 mm) sieve to separate and remove the fines. The chips had dimensions of approximately 5.7 mm x 1.9 mm x 1.7 mm.

Methods

Fiber biometry

The biometry of fibers was measured from macerated samples treated with glacial acetic acid and 20% hydrogen peroxide (1:1 v/v) in an oven at 60 ºC for 48 h. Fiber length (L), diameter (D), and lumen width (d) were measured from 40 unbroken fibers *per* sample using a semi-automated image analyzer system (Leitz-ASM 68K; Wetzlar, Germany). Diameter and lumen width were measured at mid-length of the fibers, and the cell-wall thickness (w) was calculated as (D-d)/2. The following morphological parameters were calculated: Runkel number (2w/d), slenderness (L/D), coefficient of flexibility (d/D x 100), wall rigidity (w/D), Luce's shape factor $((D^2-d^2)/(D^2+d^2))$, and solids factor $((D^2-d^2) \times L)$

The morphological properties of the pulp fibers, *i.e.*, fiber length, width, coarseness, kinked fibers, and curl, were evaluated with a MORFI LB01 Fiber Size Analyzer (TECHPAP, France).

Pulping

Kraft and ASAM pulping experiments were conducted with 100-mL stainless steel autoclaves rotated in an oil bath equipped with a temperature controller; experiments were conducted with 5 g of stumpwood chips. The pulpings were done isothermically at a selected maximum temperature with a heating time to temperature of 5 min. The values of the process variables are given in Table 1.

The pulping experiments were done using the stumpwood samples and the stumpwood extracted samples in order to avoid the influence of the extractives during delignification. The removal of extractives from the stumpwood samples was achieved by successive and complete extraction with dichloromethane, ethanol, and water in a Soxhlet apparatus (adapted from TAPPI 204 om-88 1994).

At the end of pulping, the autoclaves were immersed in ice to stop the reaction. The pulps were defibrated with a blender, thoroughly washed with deionized hot water, and air-dried in an acclimatized room (55% relative humidity and 25 ºC). The yield was calculated after oven drying at 100 ± 2 ºC. All pulping experiments were replicated, and yield results accepted for mean calculation if the yield difference between the two types of samples was lower or equal to 0.5%; otherwise pulping was repeated.

The degree of delignification was determined by kappa number, measured in accordance with TAPPI Test Standard T 236 cm-85 (1994) with an automatic titrator (TitraLab, Radiometer Analytical; France). Intrinsic viscosity (η) was determined according to SCAN 1998. Paper color was measured with a Minolta CM-3630 (d/0º) spectrometer (Japan) using CIE 1976 Lab color space coordinates (L^*,a^*,b^*) (ISO 11664-42008 1976); ISO brightness (Tappi Test Standard T 525 om-92 1994) was also measured.

The statistical analyses were performed using SPSS® version 22.0 Statistics (IBM; USA) and the 0.05 level used as the criterion of a significant test.

Table 1. Delignification Parameters for Kraft and ASAM Processes

	Kraft process	ASAM process
Alkali charge, % (as Na_2O) (based on o.d. wood)	25	25
Na_2SO_3/NaOH	-	70:30
Sulfidity (%)	30	-
Methanol, vol % (based on total pulping liquor)	-	30
Anthraquinone, % (based on o.d. wood)	-	0.1
Liquor to wood ratio (mL/g)	5	5
Maximum temperature (°C)	170	170
Time (min)	90	90

RESULTS AND DISCUSSION

Fiber Biomorphology

The biometric characteristics of the fibers (*e.g.*, length, diameter, and wall thickness) are important parameters for assessing the pulp quality of the lignocellulose raw materials. Table 2 summarizes the biometric data and the fiber ratios of *E. globulus* stumpwood.

Table 2. Biometric Data of Fibers and Fiber Morphological Parameters of *Eucalyptus globulus* Stumps Collected at Six Sites in Portugal and Mean and Standard Deviation

	[F]	[HF]	[SO]	[T]	[L]	[VA]	Mean ± std
Length (mm)	0.896	1.121	0.836	0.812	1.022	0.948	**0.930 ± 0.19**
Diameter (μm)	20.2	22.2	22.5	21.7	22.5	19.0	**21.4 ± 4.3**
Lumen width (μm)	8.7	7.7	9.4	9.2	9.7	9.4	**9.1 ± 3.0**
Cell-wall thickness (μm)	5.8	7.2	6.5	5.8	6.4	4.8	**6.1 ± 1.7**
Runkel ratio	1.3	1.9	1.4	1.3	1.3	1.0	**1.4 ± 0.3**
Slenderness ratio	44.3	50.6	37.2	35.1	45.4	49.8	**43.7 ± 6.4**
Flexibility coefficient (%)	42.9	34.9	42.0	42.4	43.3	49.4	**42.5 ± 4.6**
Luce's shape factor	0.69	0.79	0.70	0.70	0.69	0.61	**0.69 ± 0.06**
Solids factor	0.30	0.49	0.35	0.31	0.42	0.26	**0.35 ± 0.08**

Mean for each site and general mean and standard deviation

The biometric values and the calculated ratios did not vary significantly among the sites. The fiber length ranged from 1.12 mm in [HF] to 0.81 mm in [T], and the diameter ranged from 22.5 µm (in [SO] and [L]) to 19.0 µm (in [VA]). The highest value for cell-wall thickness (7.2 µm) was registered in [HF], and the lowest (4.8 µm) was found at [VA].

On average, the stumpwood was found to be composed of fibers with a mean length of 0.930 mm, diameter of 21.4 µm, lumen width of 9.1 µm, and cell-wall thickness of 6.1 µm. These mean values are in accordance with the literature data reported for *E. globulus* stemwood fibers: 0.78 to 1.12 mm for length, 12 to 21.3 µm for diameter, 4 to 9.5 µm for lumen width, and 2.6 to 12 µm for cell-wall thickness (Miranda *et al.* 2001; Miranda *et al.* 2003; Miranda and Pereira 2002; Pereira *et al.* 2011; Santos *et al.* 2008).

The Runkel ratio is related to pulp yield (Ona *et al.* 2001) and paper conformability (Bamber 1985), with values ranging from 0.25 to 5.0 depending on the species (Singh *et al.* 1991). Thick-walled fibers tend to retain their tubular structure during paper formation, which promotes less surface contact for fiber-to-fiber bonding, thus diminishing the bursting strength, tensile strength, and folding endurance of the paper (Dutt *et al.* 2004; 2009). Among the six sites, the Runkel ratio varied between 1.0 and 1.9, with a mean of 1.4. In *E. globulus*, Ohshima *et al.* (2005) reported values from 0.54 to 0.67 for 14-year-old trees, and Pirralho *et al.* (2013) reported a Runkel ratio of 1.75 for 4-year-old trees.

The slenderness ratio has been related to fiber flexibility; higher values of this parameter are indicative of better tensile and tear resistance (Ona *et al.* 2001). In the present study, the highest value of the slenderness ratio (50.6) was observed in [HF], and the lowest (35.1) was found in [T]. These observed values are smaller than those reported by Ohshima *et al.* (2005) for *E. globulus* trees (57.7 and 59.9).

Regarding the Luce's shape factor and solids factor, both are correlated with paper sheet density and breaking length (Ohshima *et al.* 2005). In the present study, the mean values were, respectively, 0.69 and 0.35, with the highest values (0.79 and 0.49, respectively) observed in [HF].

Previously, Gominho *et al.* (2012) characterized the stumps used in this pulping study by summative chemical analysis (Table 3).

Table 3. Chemical Composition (% of oven dry mass) of *Eucalyptus globulus* Stumps Collected at Six Sites in Portugal*

	[F]	[HF]	[SO]	[T]	[L]	[VA]	Mean ± std
Ash	**0.6**	**0.4**	**0.6**	**0.3**	**0.4**	**0.2**	**0.4 ± 0.2**
Extractives	**14.9**	**11.3**	**17.4**	**16.9**	**17.1**	**13.0**	**15.1 ± 2.5**
Dichloromethane	0.5	0.5	0.5	0.1	0.5	0.4	0.4 ± 0.2
Ethanol	10.6	6.8	12.1	12.5	12.4	8.4	10.5 ± 2.4
Water	3.7	3.8	4.3	4.0	4.0	4.3	4.0 ± 0.2
Lignin	**24.9**	**25.5**	**24.0**	**24.4**	**24.8**	**25.1**	**24.8 ± 0.5**
Klason	22.2	22.1	21.4	21.7	21.9	21.8	21.9 ± 0.3
Acid Soluble	2.7	3.4	2.6	2.7	2.7	3.3	2.9 ± 0.4
Holocelullose	**67.5**	**71.3**	**64.3**	**64.7**	**65.5**	**68.9**	**67.0 ± 2.7**
***α*-cellulose**	**56.9**	**56.1**	**55.4**	**57.1**	**60.4**	**58.1**	**57.3 ± 1.8**
*Data from Gominho *et al.* (2012)							

Compared to the stemwood, the stumpwood exhibited a higher content of total extractives (15.1%), of which the main contribution was from ethanol-soluble compounds (10.5%); similar values in total lignin (24.8%) and holocellulose (67%) components were observed.

Pulping

Table 4 summarizes the pulp yields (based on the original dry mass) obtained from the different samples and pulping processes (kraft and ASAM), as well as the chemical properties and brightness of the resulting unbleached pulps. The two processes produced unbleached pulps with an average yield over 40%. With ASAM pulping process, higher yield values were always obtained when compared to the kraft process (an average of 49.3% and 42.7%, respectively). As expected, when using an extractive-free raw material, the pulp yield increased (51.7% and 47.5% for ASAM and kraft, respectively). A similar behavior was reported for *E. globulus* wood, with higher yields of ASAM pulps when compared with kraft pulps (59.2% *vs.* 50.0%) (Miranda and Pereira 2002), and by Khristova *et al.* (2006) for *E. camaldulensis*, *E. microtheca*, *E. tereticornis*, and *E. citriodora* (44.0%, 44.4%, 43.3%, and 47.0% *vs.* 46.4%, 47.3%, 45.6%, and 50.1%, respectively). The ASAM process afforded higher kappa number pulps when compared to the kraft process (mean of 36 *vs.* 14, respectively); the kappa number decreased when pulping the extractive-free stumpwood samples (mean of 18 *vs.* 11, respectively). The pulp brightness varied inversely to the kappa number, in relation to the residual lignin content.

Table 4. Yield, Chemical Properties, and Brightness of Pulps made from *Eucalyptus globulus* Stumps Collected at Six Sites in Portugal and Mean and Standard Deviation

	[F]	**[HF]**	**[SO]**	**[T]**	**[L]**	**[VA]**	**Mean ± std**
Kraft							
Yield (%)*	44.1	44.7	39.2	40.4	45.3	42.8	**42.7 ± 2.5**
Kappa number	10	11	18	17	13	16	**14 ± 3.0**
Viscosity (mL/g)	919	913	952	1004	949	908	**941 ± 36**
Brightness (%)	21.7	22.3	28.6	29.0	25.8	29.3	**25.9 ± 3.3**
Kraft $_{Ext}$							
Yield (%)*	48.2	48.3	44.9	47.0	48.7	47.8	**47.5 ± 1.4**
Kappa number	12	10	16	9	6	10	**11 ± 3.0**
Viscosity (mL/g)	844	817	846	863	890	813	**845 ± 29**
Brightness (%)	31.1	34.0	28.0	27.1	30.5	34.2	**30.8 ± 5.0**
ASAM							
Yield (%)*	50.9	51.1	46.5	47.5	50.9	48.9	**49.3 ± 2.0**
Kappa number	40	19	44	34	37	40	**36 ± 9.0**
Viscosity (mL/g)	917	1056	787	822	1052	938	**929 ± 112**
Brightness (%)	23.7	32.9	18.8	20.7	21.0	24.4	**23.6 ± 2.9**
ASAM $_{Ext}$							
Yield (%)*	53.4	53.4	48.8	49.9	53.1	52.0	**51.7 ± 2.0**
Kappa number	17	18	17	23	19	23	**18 ± 6.0**
Viscosity (mL/g)	913	1128	925	805	1233	1016	**1004 ± 156**
Brightness (%)	36.1	45.1	34.0	31.4	31.5	36.5	**35.8 ± 5.1**

* - based on the original dry mass

The influence of the pulping process and of the presence of extractives in the initial material on the pulps' intrinsic viscosities was not very clear from all the sites; for the kraft pulps, the mean viscosity decreased from 941 to 845 mL/g, while for ASAM pulps, it increased from 924 to 1004 mL/g for unextracted *vs.* extracted, respectively. In general, the kraft pulps made from stumpwood had lower yields and brightness values, and higher kappa numbers when compared with those of stemwood. This has been observed by Keays and Hatton (1971) with western hemlock (*Tsuga heterophylla*), Hatton and Keays (1972) with Douglas fir (*Pseudotsuga menziesii*), and Peckham and McKee (1975) with slash pine (*Pinus elliottii*).

Regarding the ease of pulping, some differences were found across the sites. The samples collected at [HF] showed the best response, mainly with the ASAM process for unextracted and extractive-free stumpwood: highest yields (51.1% and 53.4%), viscosity (1056 and 1128 mL/g), and brightness (32.9% and 45.1%), and lowest kappa number (19 and 18). The values are in accordance with the chemical composition of the material of this site, which had the highest holocelullose content (71.3%) and the lowest extractives content (11.3%) (Table 3).

The color parameters (CIE *L**, *a**, *b**) of the unbleached stumpwood pulps (Fig. 1) showed a small variation among the sites. The extracted stumpwood pulps (kraft and ASAM) produced pulps with higher *L** values. The kraft pulps showed higher values and little dispersion for the *a** parameter (3.5 to 4.5) when compared with the ASAM pulps. For the *b** parameter, the average value was similar for both types of pulps (13.4 and 12.9), but the ASAM pulps showed higher dispersion of values (11 to 15). The positive influence of extractives removal on the color of the unbleached pulp was also reported by Lourenço *et al.* (2008) and Baptista *et al.* (2006).

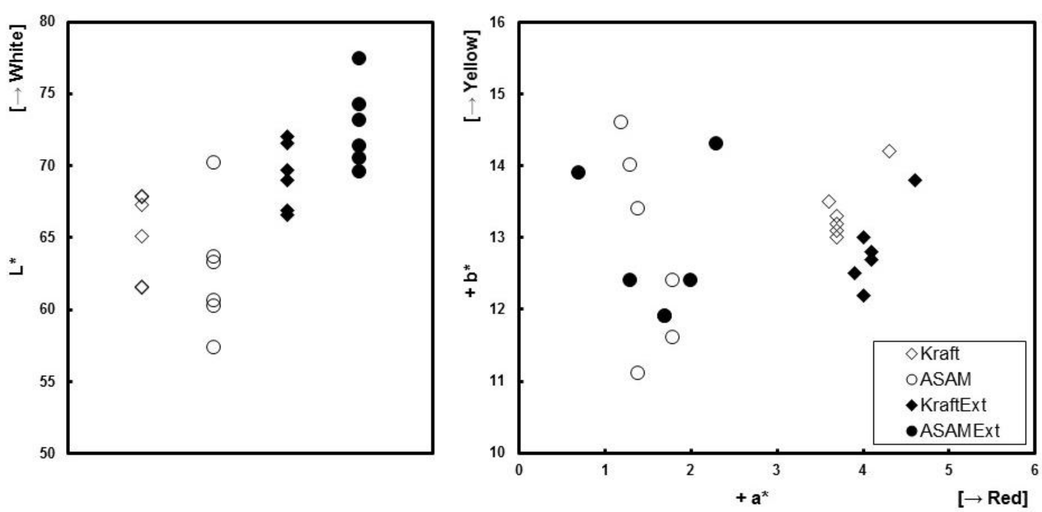

Fig. 1. Color values (CIE parameters *L***a***b**) from unbleached kraft and ASAM pulps of *Eucalyptus globulus* stumps collected at six sites in Portugal

Pulp Fiber Characteristics

Table 5 summarizes the morphological properties of the unbleached kraft and ASAM pulps obtained with stumpwood. The number of fibers per gram of pulp (million/g) varied from 12.8 to 17.6 and 12.6 to 16.4, respectively, for kraft and ASAM pulps, and the mean length (weighted in length) varied from 0.714 mm to 0.836 mm and 0.753 mm to 0.894 mm, respectively. Baptista *et al.* (2014) for *E. globulus* wood reported values of mean length between 0.798 mm to 0.770 mm. The fiber width was greater than 20.5 µm, a value higher than that reported for *E. globulus* wood pulp (18.2 µm) (Baptista *et al.* 2014).

The presence of fines in the pulps was similar between sites and higher for the kraft pulps, in accordance with the higher degree of delignification in comparison with the ASAM pulps.

Table 5. Morphological Properties of Unbleached Pulp Fibers of *Eucalyptus globulus* Stumps

	[F]	[HF]	[SO]	[T]	[L]	[VA]	Mean ± std
Kraft							
Fibers (million/g)	16.3	17.3	12.8	17.6	16.3	15.7	16.0 ± 1.72
Length, weighted in number (mm)	0.662	0.617	0.670	0.591	0.633	0.673	0.6 ± 0.03
Length, weighted in length (mm)	0.816	0.738	0.836	0.714	0.764	0.833	0.8 ± 0.05
Width (µm)	20.5	20.9	22.6	21.2	21.6	20.7	21.3 ± 0.77
Coarseness (mg/m)	0.088	0.092	0.115	0.094	0.095	0.093	0.096 ± 0.01
Kinked fibers (%)	17.7	15.8	20.0	11.7	17.4	17.3	16.7 ± 2.78
Curl %	5.2	5.1	5.7	4.5	5.3	5.5	5.2 ± 0.42
Fines (in area)	14.1	15.0	9.4	15.3	12.8	12.9	13.3 ± 2.14
ASAM							
Fibers (million/g)	13.0	16.4	13.5	16.3	12.6	16.0	14.6 ± 1.78
Length, weighted in number (mm)	0.645	0.634	0.625	0.627	0.718	0.629	0.6 ± 0.04
Length, weighted in length (mm)	0.779	0.761	0.753	0.757	0.894	0.753	0.8 ± 0.06
Width (µm)	25.2	22.5	25.2	22.5	22.7	22.1	23.4 ± 1.40
Coarseness (mg/m)	0.119	0.095	0.118	0.098	0.110	0.090	0.105 ± 0.01
Kinked fibers (%)	18.3	13.5	14.7	15.7	18.1	17.5	16.3 ± 1.97
Curl %	5.6	4.8	5.1	5.1	5.7	5.2	5.2 ± 0.33
Fines (in area)	9.4	12.3	7.1	12.0	12.2	11.5	10.8 ± 2.10

Fiber coarseness has an important effect on paper properties. Seth (1990) demonstrated that coarser fibers have thicker walls, which consequently have smaller specific surface area. In the present study, the coarseness of kraft pulps was 0.096 mg/m, while for ASAM pulps it was 0.105 mg/g, which was in accordance with the pulps' yield. Those values are slightly higher (due to the wall width) compared with the 0.068 mg/m value for commercial *E. globulus* pulps (Baptista *et al.* 2014). Nevertheless, Santos *et al.* (2008) observed a positive linearity in *E. globulus* between coarseness and wood basic density (0.051 mg/m and 0.072 mg/m for 0.467 g/cm^3 and 0.600 g/cm^3, respectively). This behavior can explain the higher values found in stumpwood pulps, as the mean basic density of the raw material was 0.63 g/cm^3 (Gominho *et al.* 2012).

Because of their thick-walled fibers, the stumpwood pulps presented lower values for curl (5.2% for kraft and ASAM processes) and kinked fibers (16.7% and 16.3%, respectively) than the eucalypt wood pulp fibers (7.3% and 28.7%, respectively) (Baptista *et al.* 2014).

CONCLUSIONS

1. This study demonstrated that stumpwood of *Eucalyptus globulus* could be an interesting raw material for papermaking fibers.
2. The stumpwood fibers exhibited biometric features similar to those found in mature *E. globulus* trees; namely, they were characterized by thick cell walls. Fiber variability among collection sites was small, which suggested that stumpwood can be a homogeneous feedstock.
3. Unbleached chemical pulps were produced from stumpwood using standard pulping conditions of kraft and ASAM processes with yields over 40%, which varied across sites due to the material's chemical composition variation.
4. ASAM pulps presented higher yield values (based on the original dry mass) when compared to kraft pulps. The removal of extractives prior to pulping increased the pulp yield.
5. The stumpwood pulps showed high coarseness, low curl, and kinked fibers, which is indicative of a good papermaking material.

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