Performance of *Schizolobium amazonicum* Wood in Bleached Kraft Pulp Production

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This study aimed to evaluate the characteristics of *Schizolobium amazonicum* wood, specifically its performance in bleached kraft pulp production and the characteristics of its pulp. Chips of *Schizolobium amazonicum* and *Eucalyptus grandis* x *Eucalyptus urophylla* (reference) were used. The following parameters were evaluated in the wood: basic density, total extractives, total lignin, holocellulose, and fiber morphology. The pulping simulations were carried out in a laboratory digester, with parameters set to obtain pulp with kappa number 19 ± 0.5. Both pulps were bleached in a PFI mill and submitted to physical-mechanical tests. The results showed that *S*. *amazonicum* wood has low basic density and higher content of extractives when compared to *E. grandis* x *E. urophylla* wood. For pulping, *S*. *amazonicum* required higher alkali charge and H factor to achieve the same delignification level of *E. grandis* x *E. urophylla*, resulting in a lower yield, pulp with lower viscosity, and higher wood specific consumption. During bleaching, the brightness gain and final viscosity of *S*. *amazonicum* pulp were lower than *E. grandis* x *E. urophylla* pulp. Moreover, *S*. *amazonicum* pulp had worse physical-mechanical characteristics than *E. grandis* x *E. urophylla*.

Keywords: Kraft pulping; Hardwood; Bleaching; Physical-mechanical tests

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INTRODUCTION

The search for new species of hardwood pulp for production is important to the pulp and paper industry, both in terms of demand for specific types of cellulosic pulp and the possibility for expansion in regions suitable for the production of planted forests. In Brazil, an important world producer of *E. grandis* x *E. urophylla* pulp, *Schizolobium amazonicum* (common name paricá) wood can be an alternative feedstock for hardwood pulp production.

Native to the Amazon, *S*. *amazonicum* has a planted area of 80,000 hectares in Brazil (ABRAF 2013) and shows technological potential and silviculture advantages, such as rapid growth and nitrogen fixing in the soil. In addition, it stands out for its seed abundance, high germination degree, rapid growth, good stalk shape, and natural pruning.

According to Terezo (2010), *S*. *amazonicum* became a viable alternative for the implementation of newly planted forests in the northern and central-western regions of Brazil in the mid-1990s. Its wood is light, with an approximate basic density of 0.300 g/cm³ (Silva *et al*. 2013). It has a clear coloration, with excellent quality for the furniture and plywood industries (Colli 2007). It is used to make matchsticks, toys, mockups, lightweight packaging, canoes, linings, inner panels and doors, concrete forms, laminates, and plywood. According to Terezo and Szücs (2008), an average increase of 35 m³ per hectare per year has been observed for *S. amazonicum*. Vidaurre *et al*. (2012) reinforced that the paricá growth rate is, on average, 30 to 35 m³ per hectare per year, even without the adoption of breeding programs commonly used for large-scale crops in Brazil.

S. amazonicum as raw material for the pulp and paper industry has not been widely studied thus far. Segura and Silva Júnior (2010) evaluated the technological characteristics of this wood species, comparing it with *E. grandis* x *E. urophylla* and *Acacia mearnsii*. The authors showed that the *S. amazonicum* wood is less dense than others with a higher extractives content. In addition, it had similar lignin and carbohydrate contents as *E. grandis* x *E. urophylla* wood. However, *S. amazonicum* stood out from the others in fiber evaluation, in which it had a greater length and width of fibers, greater flexibility coefficient, and lower Runkel index.

According to Vidaurre (2010), the low basic density of *S. amazonicum* wood makes the genetic improvement of this species necessary for its use in the pulp and paper industry. The author mentions that *S. amazonicum* wood presents a higher lignin content than *E. grandis* x *E. urophylla* wood.

In this context, the objective of this work was to characterize the wood of *Schizolobium amazonicum* for pulp production, analyzing the wood's performance in kraft pulping and elemental chlorine free (ECF) bleaching processes, in addition to evaluating the physical-mechanical properties of its bleached pulp.

EXPERIMENTAL

Materials

Schizolobium amazonicum chips from commercial crops of seven-year-old trees in Pará State, Brazil were used. As reference material, *E. grandis* x *E. urophylla* chips from commercial crops with six-year-old trees planted in São Paulo State were used.

Methods

The parameters determined in the wood were basic density (NBR 11941 2003), fiber dimensions (International Association of Wood Anatomy 1989) considering length, width, and lumen diameter parameters, total extractive content (TAPPI T204 2007), and total lignin (klason lignin + soluble lignin) (TAPPI T222 2007). Wall thickness, wall fraction, and holocellulose content were calculated according to the equations below:

$$WT = \frac{FW - LD}{2} \tag{1}$$

$$WF\ (\%) = \frac{2 \cdot WT}{FW} x100 \tag{2}$$

where *WT* is wall thickness (µm), *FW* is fiber width (µm), *LD* is lumen diameter (µm), and *WF* is wall fraction (%); and

$$Holo\ (\%) = 100 - (TE\ (\%) + LT\ (\%)) \tag{3}$$

where *LT* is total lignin content (%), *Holo* is holocellulose content (%), and *TE* is total extractive content (%).

The pulping was performed in a forced circulation digester with a capacity of 10 liters and heat exchangers for heating. The pulping conditions were adjusted in order to obtain a pulp with kappa number of 18.5 ± 0.5, and the trials were made in duplicates. After cooking, the pulps were thoroughly washed, and the following parameters were determined: total yield, screened yield, kappa number (TAPPI T236 2007), hexenuronic acids (TAPPI T282 2007), viscosity (TAPPI T230 2007), pulp brightness (ISO 2470 1999), and selectivity of the pulping process (ratio between pulp viscosity and kappa number). Wood specific consumption (WSC) was calculated as follows,

$$WSC = \left(\frac{1}{BD \cdot SY} \right) \times 0.9 \tag{4}$$

where *WSC* is wood specific consumption (m³/adt), *BD* is basic density (g/cm³), *SY* is screened yield and 0.9 is the conversion from oven-dried to air-dried mass.

The pulps were subjected to oxygen delignification at a consistency of 10% and a temperature of 100 °C for 60 min with pressure of 5.5 kg/cm³ of oxygen and 20 kg/t of sodium hydroxide. After delignification, the following parameters were determined: kappa number (TAPPI T236 2007), hexenuronic acids content (TAPPI T282 2007), viscosity (TAPPI T230 2007), and pulp brightness. Delignification efficiency was calculated as follows:

$$Efficiency = \frac{IK - FK}{IK} x100 \tag{5}$$

where *Efficiency* is the oxygen delignification efficiency, *IK* is the brown pulp kappa number, and *FK* is the pulp kappa number after oxygen pre-delignification.

After the oxygen delignification *S. amazonicum* pulp was bleached using the D0 Ep D1 P sequence, while *E. grandis* x *E. urophylla* pulp was bleaching in a A/D Eop D P sequence. The bleaching conditions are summarized on Table 1 and Table 2.

After the bleaching process, the pulp brightness was determined. The bleached pulps were subjected to a refining process at 750 and 3000 rpm in a PFI mill in duplicates. In pulps without refining and at each refining level, the following parameters were determined: drainability (ISO 5267-1 1999), tensile index (ISO 1924-3 2005), burst index (ISO 2758 2014), tear index (ISO 1974 2012), Klemm capillarity (ISO 8787 1986), and specific volume (ISO 534 2011).

Table 1. *S. amazonicum* Bleaching Conditions

Parameter	D	Ep	D1	P
Time (min.)	60	60	180	120
Temperature (ºC)	70	70	80	80
Consistency, %	10	10	10	10
Chlorine Dioxide, kg/t	kf=0.24*	-	4	-
Hydrogen Peroxide, kg/t	-	5	-	5
Sulfuric Acid, kg/t	6	-	-	-
Sodium Hydroxide, kg/t	-	8	-	5

*Chlorine dioxide charge using kappa factor (kf): *(delignified pulp kappa x kf x 10) / 2.63*

Table 2. *E*. *grandis* x *E*. *urophylla* Bleaching Conditions

Parameter	A/D	Eop	D	P
Time (min.)	120+13	60	120	120
Temperature (ºC)	90+85	85	75	80
Consistency, %	10	10	10	10
Chlorine Dioxide, kg/t	kf=0.2*	-	5	-
Hydrogen Peroxide, kg/t	-	5	-	3
Sulfuric Acid, kg/t	6	-	-	-
Sodium Hydroxide, kg/t	-	8	-	5
Oxygen pressure, kg/cm²	-	5	-	-

*Chlorine dioxide charge using kappa factor (kf): *(delignified pulp kappa x kf x 10) / 2.63*

RESULTS AND DISCUSSION

Wood Characterization

Basic density is a key parameter in the wood quality assessment for pulp production because it provides important information about chip impregnation, digester volumetric efficiency, and process yield. According to Queiroz *et al*. (2004), the basic density is related to the pulp production and its physical-mechanical properties. The basic density analysis results are shown in Table 3.

Table 3. Wood Basic Density

Parameter	*S. amazonicum*	*E. grandis* x *E. urophylla*
Basic density (g·cm^{-3})	0.347	0.469

S. *amazonicum* wood presented a lower basic density than the *E. grandis* x *E. urophylla* wood, used as a reference. The low basic density of *S*. *amazonicum* indicates a higher wood specific consumption (Maron and Neves 2004), which may negatively impact the pulping process results in economic terms since the wood for pulp production has its commercial value determined on a volumetric basis. Woods with low basic densities have increased pore volumes and consequently a higher absorption and retention capacity for the cooking liquor. Therefore, during the pulping process of low basic density wood, it is usually necessary to increase the liquor-to-wood ratio, resulting in higher power consumption due to the higher liquid mass for heating, as well as the higher volume of black liquor for the evaporation stage.

Another important feature in the wood quality assessment for the pulping process is the chemical composition. Lignin removal, the main goal of the pulping process, allows the individualization of the wood's anatomical elements. Therefore, a low content of lignin and extractives improves the pulping performance and reduces reagents consumption (Mokfienski *et al*. 2008). Extractives are also harmful, since they consume alkali and cause incrustation on industrial equipment, and may even contaminate the pulp, reducing its quality and commercial value (Queiroz *et al*. 2004). The holocellulose content is the sum of carbohydrates present in the wood and its quantity is directly related to the process yield (Santos and Sansígolo 2007). Table 4 shows the wood chemical composition results.

Table 4. Wood Chemical Composition

Component	*S. amazonicum*	*E. grandis* x *E. urophylla*
Total extractives (%)	5.42	3.06
Total lignin (%)	27.32	28.09
Holocellulose (%)	67.26	68.85

S. amazonicum wood had a higher extractives content and lower holocellulose ratio when compared to *E. grandis* x *E. urophylla* wood. The chemical composition results of *S. amazonicum* and *E. grandis* x *E. urophylla* woods were similar to the results found by other authors. Analyzing 10 *Eucalyptus* clones, Gomide *et al*. (2005) found an average 3.0% of extractives and 29.3% of lignin. Silva *et al*. (2013) studied *S. amazonicum* wood and reported 5.3% of extractives and 25.7% of lignin for this species. The fiber dimensions are also wood quality indicators for pulp production, since the pulp physical-mechanical properties are related to these wood features. The fiber dimension results can be observed in Table 5.

Table 5. Fiber Dimensions and Its Relations

Dimensions/Relation	*S. amazonicum*	*E. grandis* x *E. urophylla*
Length (mm)	1.21	1.04
Width (µm)	34.04	20.83
Lumen diameter (µm)	26.13	13.41
Wall thickness (µm)	3.96	3.71
Wall fraction (%)	24	36

According to Hortal (1988), fiber morphology has a direct relationship to pulp and paper resistance. Dinwoodie (1965) mentions fiber intrinsic resistance, density, and length as the three main factors that control the paper mechanical properties. *S. amazonicum* fibers have higher length, width, and lumen diameters than *E. grandis* x *E. urophylla* wood.

On the other hand, *E. grandis* x *E. urophylla* fibers have a higher wall fraction, a parameter directly related to higher basic density. The morphology results of *S. amazonicum* and *E. grandis* x *E. urophylla* fibers are similar to what is described in the literature. Vidaurre (2010) described length of 1.09 cm, width of 32.8 µm, lumen diameter of 25.1 µm and wall thickness of 3.9 for *S. amazonicum* fibers from seven-year-old trees. Dutt and Tyagi (2011) found fibers of *Eucalyptus* with 0.92, 20.12 µm, and 14.32 of length, diameter, and lumen diameter, respectively.

Pulping

As mentioned before, the pulping conditions were adjusted to obtain pulps with kappa number 18.5 ± 0.5 for both wood species. The pulping results are in Table 6.

In the kraft pulping process, the *S. amazonicum* wood demanded a higher alkaline charge and H factor than *E. grandis* x *E. urophylla* wood for the same delignification level (kappa 19 ± 0.5). For *S. amazonicum*, the active alkali applied was 23.5% and the H factor 2,070. However, for *E. grandis* x *E. urophylla* wood these parameters were 18.0% and 775, respectively. The need for an increased wood/liquor ratio and higher heating time has been noted in *S. amazonicum* wood cooking, facts related to its low density.

Table 6. Pulping Process Conditions and Results

Parameter	*S. amazonicum*	*E. grandis* x *E. urophylla*
Kappa number	19.0	18.0
Active Alkali (NaOH base) (%)	23.5	18.2
Liquor/wood ratio (L/kg)	5	4
Heating time (min)	120	90
Cooking time (min)	120	60
Maximum temperature (°C)	170	166
H factor	2,070	775
Yield (%)	52.0	54.6
Reject content (%)	0.0	0.1
Screened Yield (%)	52.0	54.5
Hexenuronic acids (μmol/g)	32.9	57.0
Viscosity (cm^3/g)	709	1,099
Brightness (% ISO)	30.2	30.4
Selectivity, viscosity/kappa#	37.3	61.1
Wood specific consumption (m^3/t)	5.54	3.52

S. amazonicum wood presented a lower yield when compared to *E. grandis* x *E. urophylla* wood. This result can be attributed to the cooking conditions, especially the higher alkaline charge and H factor. The wood characteristics also have an important influence on pulping results. In this case, the wood of *S. amazonicum* presents higher extractives content and lower holocellulose than *E. grandis* x *E. urophylla*, which contributes to worse pulping results. Silva *et al*. (2013) found that for a pulp kappa number 19.6 the screened yield was 52.2% when using *S. amazonicum* core chips. *S. amazonicum* pulp viscosity was also lower than the *E. grandis* x *E. urophylla* pulp viscosity, indicating greater degradation by the cooking conditions. The greater need for an alkaline charge and H factor in the pulping process of *S. amazonicum* may be related to a possible higher content of hemicelluloses in the wood or the lower reactivity of the lignin. The pulping conditions also affected the pulping results. Based on this work, it is possible to conclude that *S. amazonicum* pulping must be optimized.

Hexenuronic acids are formed during alkaline pulping by the 4-O methyl glucuronic acids present in xylans that are influenced by cooking conditions, mainly the active alkali, sulfidity, and temperature (Costa *et al.* 2001). *S. amazonicum* pulp presented a lower hexenuronic acids content, which can be explained by the degradation of these compounds under high alkaline charge and high H factor conditions (Segura and Silva Júnior 2010).

The pulping process selectivity, *i.e.*, the relation between viscosity and kappa number, was very low for *S. amazonicum* wood. This is due to the low pulp viscosity of this species, indicating a higher degradation of *S. amazonicum* pulp in order to achieve the same delignification level of *E. grandis* x *E. urophylla* pulp.

The wood specific consumption is directly influenced by wood basic density and the pulping process yield. Considering that the wood of *S. amazonicum* shows low basic density and lower yield than the wood of *E. grandis* x *E. urophylla*, it is an indicative that there is a need for higher wood volume to produce the same amount of pulp with this species.

Oxygen Delignification and Bleaching

Table 7 shows the oxygen delignification results of *S. amazonicum* and *E. grandis* x *E. urophylla* pulps.

Table 7. Oxygen Delignification Results

Parameter	*S. amazonicum*	*E. grandis* x *E. urophylla*
Brightness (% ISO)	39.1	48.0
Viscosity (cm^3/g)	560	896
Kappa	11.3	8.5
Pre-delignification efficiency (%)	40.5	52.8
Hexenuronic acids (μmol/g)	31.1	49.1

The delignification efficiency was lower for the *S. amazonicum* pulp than *E. grandis* x *E. urophylla* pulp. The kappa number after the oxygen delignification of *S. amazonicum* was also higher than the kappa of *E. grandis* x *E. urophylla* pulp; a higher kappa number impaired its bleachability and increased chemical consumption during the bleaching process.

After oxygen delignification, *S. amazonicum* pulp presented lower brightness, viscosity, and hexenuronic acids content than the *E. grandis* x *E. urophylla* pulps (Table 8), following the trend observed in the brown stock pulps. Based on these results, it is possible to verify that the delignificated *S. amazonicum* pulp showed higher degradation than *E. grandis* x *E. urophylla* pulp, a reflection of the cooking conditions and, consequently, of the brown stock pulp characteristics.

Table 8. Bleaching Process Results

Parameter	*S. amazonicum*	*E. grandis* x *E. urophylla*
Final brightness (% ISO)	83.5	89.8
Final viscosity (cm^3/g)	499	761
H_2O_2 (kg/ADt)	10.0	8.0
ClO_2 (kg/ADt)	11.8	11.4
Total active chlorine (TAC) (kg/ADt)	51.9	46.6
Bleachability (kappa#/TAC)	0.376	0.387

The brown stock pulp brightness of both species were very similar. However, throughout oxygen delignification and bleaching, the brightness gain in *E. grandis* x *E. urophylla* pulp was slightly greater, achieving a final value of 89.8% ISO, compared to 83.5% ISO of *S. amazonicum* pulp. These differences can be explained by the distinct characteristics and different bleaching sequences of the two pulps. As *S. amazonicum* brownstock pulp presented low hexenuronic acids content, we considered that an A stage for this species was not necessary. In this way, *S. amazonicum* and *E. grandis* x *E. urophylla* were bleached in different sequences.

Despite its low brightness, *S. amazonicum* bleached pulp presented a final viscosity of 499 cm^3/g, which was much lower than the *E. grandis* x *E. urophylla* pulp viscosity of 761 cm^3/g. The pulp viscosity is indicative of pulp's degradation.

S. amazonicum pulp, showing an even lower final brightness than the *E. grandis* x *E. urophylla* pulp, consumed a higher amount of reagents during bleaching, due to its reduced bleachability.

Physical-Mechanical Tests

The physical-mechanical properties of *S. amazonicum* and *E. grandis* x *E. urophylla* pulps are shown in Figs. 1, 2, and 3.

Analyzing the physical-mechanical properties of pulps without refining, it is possible to observe that the *S. amazonicum* pulp had increased drainability compared to *E. grandis* x *E. urophylla*. This fact may be related to its higher content of fines, resulting from higher degradation and possibly a greater amount of hemicelluloses. For the *E. grandis* x *E. urophylla* pulp, 3,000 rpm were necessary to achieve 35 °SR, while the *Schizolobium amazonicum* pulp only required 750 rpm to achieve 34 °SR.

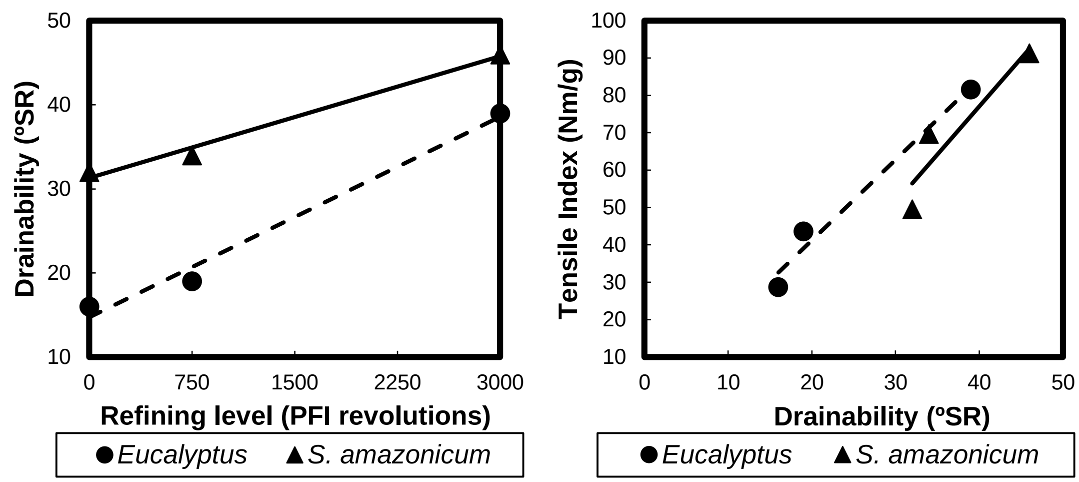

Fig. 1. Drainability and tensile index

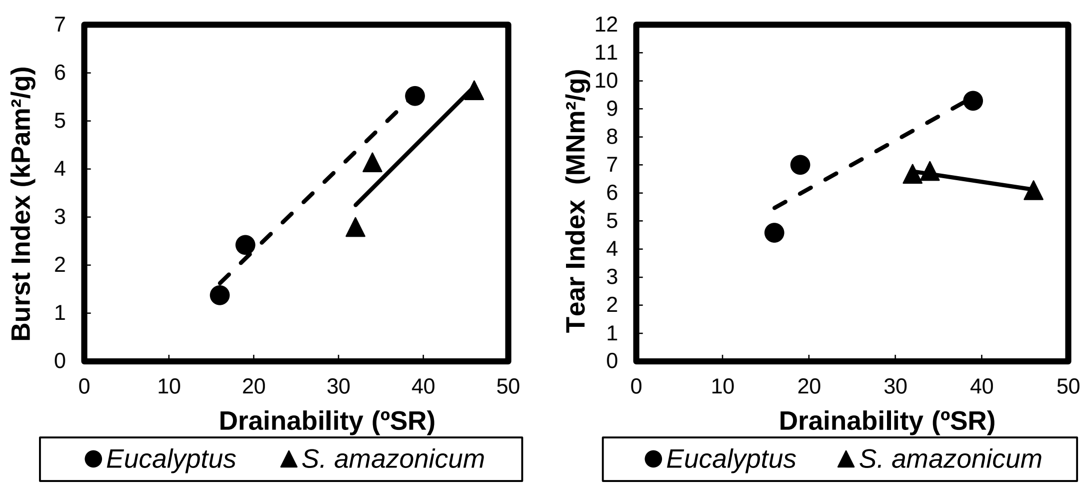

Fig. 2. Burst index and tear index

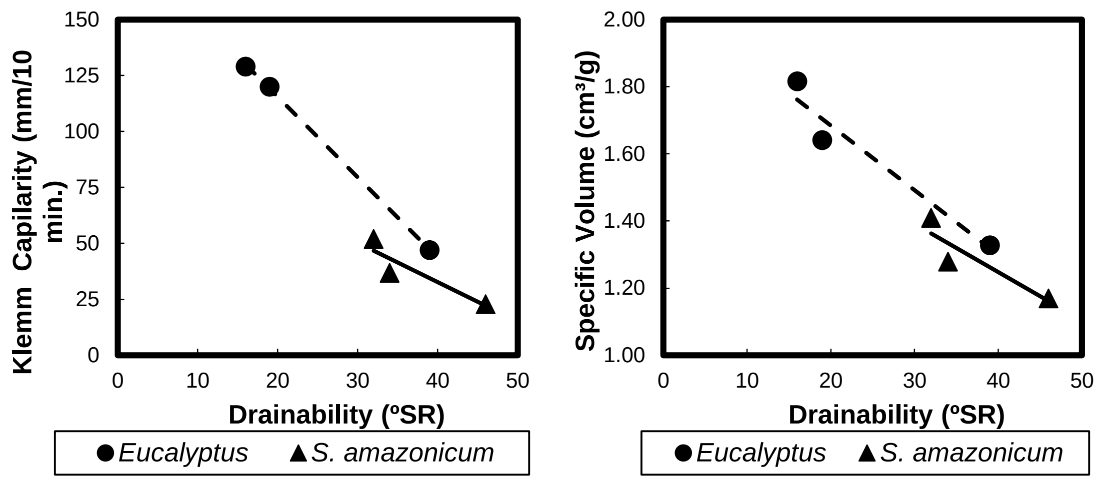

Fig. 3. Klemm capillarity and specific volume

In properties that depend on paper structure consolidation, the *S. amazonicum* pulp presented lower values. For a drainability of 35 °SR, the *E. grandis* x *E. urophylla* pulp presented a tensile index of 74.2 N/mg and burst index of 5.19 kPam²/g. In the *S. amazonicum* pulp, these values were 69.7 N/mg and 4.14 kPam²/g, respectively. Both pulps had tensile and burst indices evolution with refining.

In the tear resistance analysis, the *S. amazonicum* pulp also had values lower than *E. grandis* x *E. urophylla* pulp. While the tear resistance of *S. amazonicum* pulp was 6.79 kPam²/g with 35 °SR, this property of *E. grandis* x *E. urophylla* pulp was 9.53 kPam²/g at the same drainability level. Unlike *E. grandis* x *E. urophylla* pulp, the tear index of *S. amazonicum* is not so affected by refining evolution. It should be noted that the tear resistance is a parameter that is related to the fibers' transverse dimensions, which are of fundamental importance in short fiber pulps. As shown in Table 3, the wall fraction of *E. grandis* x *E. urophylla* fibers was higher than that of *S. amazonicum* fibers, a fact that helps explain the difference in the tear resistance between both pulps. A reduction in the tear index is related to fibers' resistance reduction (D'Almeida *et al*. 2004), which is due to increased degradation of the *S. amazonicum* pulp.

The Klemm capillarity is an important property to the pulp drying process and the use of pulp in absorbent paper production (tissue). Among unrefined pulps, a raw material normally used for tissue paper production, *E. grandis* x *E. urophylla* pulp has far superior capillarity to *S. amazonicum* pulp. During refining, this property is similar in both pulps, although it remains lower for *S. amazonicum* pulp with drainability of 35 ºSR. Both pulps have reduced capillarity with the refining evolution.

The specific volume, also known as "bulk", is a prized property by paper manufacturers. Among the refining pulps, *E. grandis* x *E. urophylla* presented greater bulk compared to *S. amazonicum* pulp, and this property in both pulps was similar in cellulosic pulp refining. At a drainability level of 35 ºSR, the specific volume of *E. grandis* x *E. urophylla* pulp is slightly higher than this property of *S. amazonicum* pulp. The differences observed between the pulps may be related to the greater wall fraction of *E. grandis* x *E. urophylla* fibers when compared to *S. amazonicum* fibers.

The results of physical tests of *E. grandis* x *E. urophylla* pulps are similar to those found by Milanez *et al*. (2008). The authors analyzed the refining effect on pulp physical characteristics and describe 74.2 Nm/g, 5.19 KPam²/g, 9.53 Nm²/kg, 29.4 mm/10 min and

1.48 cm^3/g for tensile index, burst index, tear index, Klemm capillarity, and specific volume, respectively, after 3,000 PFI revolutions.

CONCLUSIONS

1. *S. amazonicum* wood fibers had higher lumen length, width, and diameter, as well as lower wall fractions when compared to *E. grandis* x *E. urophylla* fibers.
2. *S. amazonicum* wood had lower basic density, a higher extractive content, lower holocellulose, and lower total lignin content than *E. grandis* x *E. urophylla* wood.
3. To achieve the same degree of delignification in the pulping process, *S. amazonicum* wood demanded a higher alkaline charge than did *E. grandis* x *E. urophylla* wood for the selected pulping conditions. This negatively affected the yield, pulp viscosity, and the process selectivity. *S. amazonicum* pulp had a lower amount of hexenuronic acids. In this way, the pulping conditions for *S. amazonicum* wood must be optimized to achieve better results.
4. *S. amazonicum* pulp bleaching demanded a higher amount of chemical reagents than *E. grandis* x *E. urophylla* pulp bleaching. Both the brightness and viscosity of *S. amazonicum* bleached pulps were lower than *E. grandis* x *E. urophylla* pulps. *S. amazonicum* bleached pulp presented lower refining energy consumption to achieve the same drainability when compared to *E. grandis* x *E. urophylla* pulp. *E. grandis* x *E. urophylla* bleached pulp presented higher values of tensile index, burst index, tearing index, capillarity, and specific volume when compared to *S. amazonicum* bleached pulp.
5. As the demanded bleaching chemicals are higher for *S. amazonicum* than for *E. grandis* x *E. urophylla*, the use of this wood species for bleached pulp production can be environmentally negative.
6. Compared to *E. grandis* x *E. urophylla*, *S. amazonicum* wood had poorer technological characteristics for the production of pulp and is a completely different raw-material for this industry. In this case, it is necessary to optimize the pulping conditions for this wood species.

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