Pre-hydrolysis kraft dissolving pulp from Bambusa vulgaris and Dendrocalamus asper bamboos biomass

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Abstract

In Brazil, bamboo emerges as a potential non-wood raw material as alternative lignocellulosic biomasses source, since this crop has high rusticity and productivity. It grows even in poor soil and shortage of water conditions, and it has a harvest cycle close to 2 years. This study aimed to produce dissolving pulp from the bamboo species *Bambusa vulgaris and Dendrocalamus asper* seeking to optimize the process conditions, in order to obtain a final product with the specification's parameters for viscose grade. Bamboo chips of *Bambusa vulgaris and Dendrocalamus asper* with 2 years old were submitted to pre-hydrolysis kraft pulping process. After pre-hydrolysis kraft pulping *Bambusa vulgaris* showed screened yield of 34.2% and a xylan content of 3,47% *and Dendrocalamus asper* showed screened yield of 34,7% and a xylan content of 2,65. Based on these results, only *Dendrocalamus asper* was selected and bleached. After optimizing the bleaching process the final kappa number of 0.20, viscosity of 465 dm^3/kg and 90.6% brightness were obtained for *Dendrocalamus asper*. Were achieved 1,76% of xylan, 98,1% of glycan and 0.10% of ash content. Was concluded that *Dendrolocamus asper* can be applied for the production of dissolving pulp. The CCE stage, under the established conditions, did not show to be efficient in removing the xylans from *Dendrocalamus Asper* brown pulp. On the other hand, further work is needed to optimize the main stages of the process, such as the pre-hydrolysis connected to kraft pulping, as well as the stabilization of carbohydrates chains against bleaching oxidants.

1. Introdution

The emergence of new technologies, in line with the demand for innovation and sustainability, has brought the use of lignocellulosic biomasses as an alternative raw material for non-woody fiber. Therefore, the need arose to implement the use of cellulosic biomass on an industrial scale in the most diverse sectors of the forest production chain. Among some motivating factors are the need to complement the production of wood raw material, the optimization of processes, the possible reduction of costs, competition between different forest sectors and the edaphoclimatic conditions of the planting sites.

On the world stage, Brazil is the second largest producer and largest exporter of cellulosic pulp obtained through wood delignification (IBÁ 2019). For this purpose, Eucalyptus and Pinus species are the most used worldwide. This segment currently represents about 1.3% of the Brazilian national GDP and 6.9% of the industrial GDP, and is therefore considered a sector that maximizes the country's economy. Although Brazil has a planted area of eucalyptus that exceeds 5.6 million hectares, there are factors that increase the need to obtain alternative sources of production, such as the trends of increasing wood processing costs and competition with other industrial sectors (Borges et al. 2018).

The average productivity of bamboo biomass can vary between 20 to 90 t/ha (2016). Brazil has 1.5 million hectares of native and planted bamboo forests with 258 different species. The genera Bambusa and Dendrocalamus have good agricultural productivity, 25t/ha on average (Guarnetti 2013).

Bamboo emerges as a possibility for use as an alternative lignocellulosic raw material in Brazil because it is a crop with high occurrence in Brazilian soil, short harvest cycles, good adaptability even in poorly fertile soils and high productivity per hectare (Reubens 2010; Xuhe 2003). In Brazil, according to the List of Species of Brazilian Flora, there are 258 species of bamboo and, according to data measured by the Ecological-Economic Zoning (ZEE) of Acre, this state has drawn attention for having the largest native bamboo forest in the world, presenting about 180 thousand square kilometers of forests with the presence of the plant. The use of bamboo for the production of conventional cellulosic pulp is already a reality in the Asian market. In Brazil, the company Itapajé used Bambusa vulgaris for the production of paperboard, however, the industrial application is still incipient in western countries.

Bamboo fibers have intermediate values of fiber length and wall thickness in relation to the Pinus spp. and the Eucalyptus spp. It may be used to production of short fiber pulp and long fiber pulp simultaneously (Júnior et al. 2019) This characteristic makes bamboo a good material for pulping, paper and dissolving pulp. Dissolving pulp is a chemically refined, bleached 90% pure cellulose compound with low hemicellulose and lignin content (Chen et al. 2016).End uses include such as cellophane and rayon, cellulose esters, cellulose ethers, and grafted or crosslinked cellulose derivatives.

Bamboo may be used as a potential resource for dissolving pulp production. However, its hemicellulose content is higher than that of traditional wood species. Therefore, it is challenging to use bamboo for dissolving pulp production.

Dissolving pulp quality mainly depends on the pulping process, in addition to the properties of the raw material. Currently, the pre-hydrolysis Kraft pulping process is one of the primary methods for producing dissolving pulp due to its high efficiency in lignin and hemicellulose removals (Chen et al. 2016). In addition, compared to wood, bamboo contains a higher silica content. Silica generates problems during pulping and bioconversion processes, causing complications in effluent streams. Therefore, the low silica content in raw materials is of great importance in expanding the use of bamboo.

The production of dissolving pulp is expanding in Brazil. Currently, the largest consumption of this product is concentrated in the Asian continent, representing about 77% of world demand and, due to the high capacity of forestry production, an investment of 7.5 billion reais is estimated for new projects for the production of wood. dissolving pulp in Brazil, which can generate thousands of jobs directly and indirectly (FIEP 2016).

A clear example of the expansion of the sector in the country is the association between the companies Lenzing and Duratex, creating LD Celulose Co., which will be inaugurated in 2022, in Minas Gerais.

The overall fiber yield for the production of dissolving pulp is rarely above 35% (Batalha et al. 2012), pulps must contain a high content of alpha-cellulose (95 to 98%) and relatively low contents of hemicelluloses (< 4%) and lignin (< 0.05%). The intrinsic viscosity of dissolving pulp viscose grade should be in the range of 400 to 600 mL/g (Duan et al. 2015; Strunk et al. 2012).

The PHK procedure features a combination of acidic (pre-hydrolysis) and alkaline (kraft cooking) conditions. The pre-hydrolysis step causes the depolymerization of hemicelluloses, allowing a greater degree of delignification in kraft cooking (Sixta 2006). Finally, the brown pulp is sent to the bleaching stages, in order to achieve the desired purity.

Therefore, the interest in studying the applicability of bamboo as an alternative source for the production of soluble pulp is justified, identifying the viability of the process, species that are chemically more favorable to kraft cooking and technological solutions that remedy the challenges of working with this culture.

2. Materials And Methods

2.1. Materials

For this study, the species *Bambusa vulgaris* and *Dendrocalamus asper* were selected as an alternative fibrous source. The lignocellulosic biomass used comes from Federal University of Vicosa (UFV). Vicosa city is located at Minas Gerais, between between the latitudes of 20º 60' S to 20º 90' S and between the longitudes of 43º 10' W to 42º 90' W, at an average altitude of 650 meters (Silva 2021). The predominant climate in the city is tropical, with rainfall during the summer and an average annual temperature of 19°C, ranging between 14°C and 32°C (Prado et al. 2020). The bamboo stalks collected were between 2 and 3 years old at planting, and the cut was performed above the first node.

The experiments were carried out at the Pulp and Paper Laboratory (LPC). Bamboo samples were converted into chips, with approximate dimensions of 15 mm wide, 20 mm long and 4 mm thick. Subsequently, identified and stored to ensure the integrity of the material.

2.2. Methods

To produce bamboo dissolving pulp, the pre-hydrolysis kraft (PHK) pulping process was applied. In order to select the most suitable species for production, in which it presented the predetermined final characteristics, several analyzes were carried out on the bamboo chips and pulp produced. Two different bleaching sequences were applied to the brown pulp, in which we sought to observe the efficiency of the cold alkaline extraction step during the process. Table 1 describes the parameters to be analyzed and their respective standard procedures.

Table 1

Gravimetric analyzes performed on both bamboo species

Parameter	Procedure
Black liquor pH	Tappi T211 om-93
Black liquor residual effective alkali	SCAN N2:88
Whiteness	TAPPI T452 om-99
Intrinsic Viscosity	TAPPI T230 cm-89
Carbohydrates	SCAN-CM 71:09
Kappa number	Tappi T 236 cm-85
Manual sheet formation	Tappi T 218 sp-97
Lignin	Klason method – TAPPI 222 om – 83
Extractives	TAPPI T 264 om – 82

2.2.1. Pre-hydrolysis kraft (PHK) pulping procedure

The process was carried out with a mass of 600 grams of dried chips in an MK digester, electrically heated and equipped with electronic controls connected to the computer and to peripheral equipment. The temperature data obtained were monitored every minute, making it possible to establish the profile of factor P and factor H at the end of cooking. The P factor is the relationship between time and temperature during the pre-hydrolysis stage (Jia et al. 2022). The H factor is a variable developed to express cooking time and temperature (Segura and Silva Júnior 2010). The cooking white liquor was prepared as the alkaline loading conditions of sodium hydroxide and sodium sulfide changed. The pre-hydrolysis kraft pulping procedure is described (Table 2) by four steps including (1) autohydrolysis; (2) neutralization; (3) kraft pulping and (4) washing process.

Table 2

Conditions applied during the pulping process (P factor of 1296 and H factor of 4142)

Process steps	Temperature (° C)	Time (min)	EA (%)	L/C Ratio
Autohydrolysis	170	117 + 120	-	3:1
Neutralization	170	30 + 30	3 + 3	3:1
Kraft pulping	180	15 + 120	14–24	5:1
Washing	90	15	3	6:1

Autohydrolysis aims to remove the hemicelluloses from the bamboo chips, being carried out with water at P factor of 1296. Under these conditions, acetic acid release from bamboo xylan, reducing the pH of the medium, leading to the degradation of hemicelluloses. The autohydrolysis liquor was extracted from the digester, followed for neutralization, at 170ºC. Neutralization step was being divided into two stages of 30 minutes, wherein was used liquor with EA 3.0%. The liquor from initial displacement of autohydrolysis liquor was extracted from the digester. The liquor from the second neutralization stage remained, going on to the kraft pulping stage. The kraft pulping process was carry out in order to achieve kappa number 10 ± 2, by adjusting EA charge, at a fixed H factor of 4142. Finally, washing process consists of using a liquor with 3% EA.

2.2.2. Pulp disintegration and washing

After washing the chips inside the laboratory digester, sequentially, the material was sent to the Hydro Pulper, for 2 minutes. At this stage of the process, the cellulose fibers were individualized and the black liquor contained inside the chips was diluted in water and subsequently extracted from the material.

Subsequently, the cellulosic pulp was sent to the laboratory scrubber. This equipment aims to separate the purified cellulosic pulp from the amount of waste generated, selectively removing the contaminating material from the pulp generated during the process.

The tailings can be of fibrous origin, from chips that have not been properly cooked, or of non-fibrous origin.

There are several applications for tailings, but for this to occur, a careful characterization is necessary. Among the various applications for this material, we can mention composting (Barretto 2008).

After the previous step, the tailings were removed from the scrubber and their mass was measured. Then the purified cellulosic pulp is placed in suitable nylon bags and transported to a laboratory centrifuge for 10 minutes. This step consists of removing the excess water contained in the cellulosic pulp.

The “clods” of cellulose formed during the centrifugation stage will be disintegrated, which increases the specific surface area of the material, which in turn facilitates its drying, increasing the reactivity of the particles in future analyses.

To perform the kappa number analysis, a sheet of cellulose fibers was produced in a sheet former.

The kappa number is the volume, in milliliters, of a 0.1N KmnO4 solution needed to react with the lignin present in an amount in grams of cellulosic pulp (Colodette et al. 2014).

2.2.3. Gravimetric analysis

In order to evaluate the results of dissolving pulp production, the total yield and screened yield were measured, all of them on a dry wood mass basis. Respectively, these parameters can be measured according to equations (3), (4) and (5).

Equation 3:

$$Y_T\,(\%) = \frac{m_{DCel}}{m_{DChips}} \times 100$$

Where Y_T (%) is total yield in percentage, m_{DCel} is cellulose dry mass and m_{DChips} is chips dry mass.

Equation 4:

$$TC\,(\%) = \frac{m_{DT}}{m_{DChips}} \times 100$$

Where TC (%) is tailings content in percentage and m_{DT} is tailings dry mass.

Equation 5:

$$Y_S\,(\%) = \frac{m_{DCel_S}}{m_{DChips}} \times 100$$

Where Y_S (%) is screened yield in percentage ans m_{DCelS} is screened cellulose dry mass.

The other analyzes are described in Table 2, together with their respective standards.

2.2.4. Pulp bleaching

The bleaching of the brown pulp occurred in such a way that it was possible to optimize the use of chemical reagents, in a way that conserves the carbohydrates present in the material. The first sequence introduced was: CCE – D_0 – (EP) – D_1 – D_2. Table 3 presents the parameters of this process. During the entire procedure, the material consistency was 12.0% for the first sequence and 10.0% for the second sequence.

Table 3

General bleaching CCE – D_0 – (EP) – D_1 – D_2sequence conditions

Parameters	CCE	Do	(EP)	D_1	D_2
Consistency (%)	12	12	12	12	12
Temperature (ºC)	40	60	80	80	70
Reaction time (min)	30	60	60	180	180
ClO_2 (kg/t)	-	0,22 KN*	-	10	5
NaOH (kg/t)	80	-	10	?	?
H_2SO_4, (kg/t)	-	**	-	-	-
H_2O_2, (kg/t)	-	-	3	-	-
final pH	13,5	2,0–2,5	10,2	4,0–4,5	5,5
*KN = Kappa number; ** Use or not of H2SO4 for pH adjustment					

In a second moment, the CCE step was replaced by the use of a chelator, this sequence being described as: Q – (OO) – D_0 – (EP) – D_1 – D_2 (Table 4).

Table 4

General bleaching Q – (OO) – D_0 – (EP) – D_1 – D_2sequence conditions

Parameters	Q	(O/O)	Do	(EP)	D_1	D_2
Consistency (%)	10	10	12	12	12	12
Temperature (º C)	70	80/100	60	80	80	80
Reaction time (min)	60	15/60	60	60	120	120
Pressure (kPa)	-	600	-	-	-	-
O_2 (kg/t)	-	20	-	-	-	-
Chelator (kg/t)	6	-	-	-	-	-
ClO_2 (kg/t)	-	-	0,22 KN*	-	**	5
NaOH (kg/t)	-	20	-	10	***	***
H_2SO_4, (kg/t)	1	-	***	-	-	-
H_2O_2, (kg/t)	-	-	-	3	-	-
final pH	5	> 10,5	2–2,5	10	4–4,5	5,5
*KN = Number Kappa						
**Otimizado para cada amostra chegar na alvura 90%ISO						
*** H_2SO_4 ou NaOH para ajuste de pH						

The cold caustic extraction (CCE) step, recognized for its hemicellulose removal function, was carried out at 40ºC for 30 minutes. In this step, 80 kg/t of NaOH was added as a chemical reagent.

The delignification with chlorine dioxide (D_0) took place at a temperature of 60ºC and a time of 60 minutes. In this second step, 0.22 kg/t of ClO_2 was added to the material.

The third step, alkaline extraction with hydrogen peroxide (EP), had a temperature of 80ºC for 60 minutes, with the addition of 10 kg/t of NaOH and 3 kg/t of H_2O_2. The bleaching step with chlorine dioxide (D_1) was carried out at 80ºC for 180 minutes, with 10 kg/t of ClO_2 being added. Finally, the next step of bleaching with chlorine dioxide (D_2) was carried out at a temperature of 70ºC for 180 minutes, with the addition of 5 kg/t of ClO_2.

For the second sequence, with the replacement of the CCE step, the step containing the chelator (Q) was carried out with the temperature at 70ºC for 60 minutes. For the second stage of this sequence, the application of Oxygen (OO) was carried out in two stages, with temperatures of 80ºC and 100ºC, for 15 minutes and 60 minutes, respectively. In this step, 20 kg/t of O2 and 20 kg/t of NaOH were added.

3. Results And Discussion

3.1. Bamboo chemical composition

Among the characteristics of wood, the chemical composition can directly influence the yield of the pulp produced, the final product quality and the consumption of reagents (Bassa 2006). Figure 1 shows the values of the tests for chemical characterization of the species *Dendrocalamus asper* and *Bambusa vulgaris*.

Xylans and lignins are undesirable in this process because they decrease reactivity and act as contaminants during the process (Martino 2015). It was observed that the most present carbohydrates in bamboo chips are glycan and xylan.

Once the chemical characterization of bamboo chips was measured, the basic density, lignin content and S/G ratio were determined. These parameters are shown in Fig. 2.

Table 5

Basic density, lignin content and S/G ratio

Sample	Basic Density (kg/m3)	Lignin (%)			S/G
		Syringyl	Guaiacyl	P-Hydroxyphenyl	
D. asper	452	16,8	16,1	5,5	1,05
B. vulgaris	487	12,1	17,7	5,4	0,69

The basic density of *Bambusa vulgaris* chips is higher, which indicates that this material may have a greater resistance to the cooking liquor impregnation. The S/G ratio found for *Dendrocalamus asper* was higher, which indicates that lignin tends to be cleaved more easily, since it has a less condensed structure.

Through the analysis of ash and elemental chemical composition of the chips (Table 7) it is possible to notice very similar values between the species, especially in relation to ash and compounds insoluble in HCl.

Table 6

Analysis of ash and chips elemental chemical composition

Sample	Ashes (%)	Insoluble HCl (%)	Metals (mg/Kg)					
			Ca	Mg	Fe	Cu	Na	K
D. asper	2,47	0,27	101	146	11,59	2,34	155	111
B. vulgaris	2,47	0,22	87	151	8,66	2,53	123	111

3.2. PHK process performance

Once the cooking conditions were determined, the production process could be started. In order to compare the two bamboo species, the kappa number and the screened yield of the brown pulp were considered determinant parameters to evaluate the productive viability of the samples. Regarding *Dendrocalamus asper*, Fig. 2 shows the behavior of this species in relation to effective alkali (EA), kappa number and screened yield.

It can be seen (Fig. 2) that when the lowest level of alkaline load was applied, the sample presented higher values of kappa number and screened yield. On the other hand, under drastic cooking conditions, we obtained lower values of these same parameters. The above result is explained by the degree of degradation of lignin, cellulose and hemicellulose in the material. Under more severe conditions, the constituents of the chips remained in the pulp in smaller amounts, when compared to the milder conditions. For the species *Bambusa vulgaris* (Fig. 2b) it was observed that both parameters evaluated showed the same tendency of *Dendrocalamus asper* (Fig. 2a). In this study, the tailings content presented by the two bamboo species was 0.0%, in the entire range of applied alkaline load.

Table 7 shows the brown pulp characterization produced from the two bamboo species. Due to the comparison between them, was considered the cooking condition in which kappa number 10 ± 2 has been reached. Although the species *Bambusa vulgaris* has a lower kappa number, higher brightness and higher viscosity, it can be seen that this species has a lower level of purified yield and higher content of xylans compared to other species. Comparison between the brown pulps of different bamboo species

Table 7

Comparison between the brown pulps of different bamboo species

Sample	P Factor	Kappa number	Screened yield (%)	Brightness (%ISO)	Intrinsic Viscosity (dm^3/kg)	Insoluble Lignin (%)	Carbohydrates (%)	
							Glyc[1]	Xyl[2]
D. asper	1296	11	34,7	33,8	535	1,38	95,6	2,65
B. vulgaris	1296	12	34,2	32,8	728	1,6	94,7	3,47

1: Glycan; 2: Xylan

3.3. ECF bleaching process performance

To complete the process, these pulps were bleached, thus allowing a more accurate analysis of the samples. In table 8 we evaluate the final results, allowing the selection of the most suitable species for the production of dissolving pulp. During the bleaching process, the sequence CCE - D_0 - (EP) - D_1 - D_2 was applied. It was observed that the viscosity of the species *Dendrocalamus asper* was higher and lower carbohydrate degradation during the process. Since previously, after the PHK process, the viscosity of the species *Bambusa vulgaris* had been shown to be higher.

Table 8

Bleached pulp of different bamboo species comparison

Sample	Kappa number	Brightness (%ISO)	Intrinsic Viscosity (dm^3/kg)	Carbohydrates (%)	
				Glic[1]	Xil[2]
Dendrocalamus asper	0,20	89,6	373	97,2	2,64
Bambusa vulgaris	0,20	91,2	437	96,5	3,48
1: Glycan; 2: Xilan					

Another important parameter is the xylan content, which was higher for the species *Bambusa vulgaris*. This characteristic is considered essential for the selection and indication of the species *Dendrocalamus asper* as the best for the production of dissolving pulp, since hemicellulose is a compound considered inappropriate for the final product. It is important to emphasize that, despite using the CCE step in the process, there was no significant variation in the xylan content after the bleaching process, when compared to the content found in the brown pulp.

3.4. PHK process optimization

In this step, the autohydrolysis was replaced by an acid pre-hydrolysis, performed with the addition of 3% acid, together with the bleaching sequence Q – (OO) – D_0 – (EP) – D_1 – D_2. The comparison with the autohydrolysis process, in which the sequence CCE - D0 - (EP) - D1 - D2 was used to bleach the brown pulp, is presented in Table 9 (brown pulp) and Table 10 (bleached pulp).

Table 9

Effect of acid pre-hydrolysis on the brown pulp of *Dendrocalamus asper*

Procedure	EA%	Kappa number	P factor	H Factor	Screened yield (%)	Intrinsic Viscosity (dm^3/kg)	Carbohydrates (%)	
							Glyc[1]	Xyl[2]
Autohydrolysis	16,0	10,8	1296	4142	34,7	535	95,6	2,65
Acid pre-hydrolysis [3]	16,0	11,9	1296	4142	32,0	461	96,8	1,69
Acid pre-hydrolysis [3]	19,0	19,1	1296	802	35,0	996	95,5	1,76
Acid pre-hydrolysis [3]	19,0	13,4	260	802	42,4	1297	93,6	5,04
Acid pre-hydrolysis[4]	19,0	14,6	260	802	44,3	1279	90,5	8,30
1: Glycans 2: Xylans 3: Formic acid 4: Glacial acetic acid								

The formic acid action allowed a greater degradation of xylans. Consequently, there was a loss of screened yield. The pre-hydrolysis liquor pH was measured, showing values of 3.6 for autohydrolysis and 3.4 for acidic pre-hydrolysis. After the production of the brown pulp, the material runed on to the bleaching process in order to verify the need to implement the CCE step. The results are shown in Table 10.

Table 10

Effect of acid pre-hydrolysis on *Dendrocalamus asper* bleached pulp.

Procedure	Kappa number	Brightness (%ISO)	Intrinsic Viscosity (dm^3/kg)	Carbohydrates (%)	
				Glic[1]	Xil[2]
Autohydrolysis	0,1	89,6	373	97,2	2,64
Acid pre-hydrolysis [3]	0,1	88,7	357	98,1	1,67
Acid pre-hydrolysis [3]	0,2	90,6	465	98,1	1,76
Acid pre-hydrolysis [3]	0,2	91,9	597	94,7	4,9
Acid pre-hydrolysis[4]	0,13	91,9	563	91,6	8,1
1: Glycans 2: Xylans 3: Formic acid 4: Glacial acetic acid					

In both procedures, there were no significant losses of xylan content, evidencing that the CCE step during the brown pulp bleaching is not necessary during the process. Comparing all the results obtained, the sample in which the xylan content was equivalent to 1.76 was considered ideal, since it presented intrinsic viscosity, brightness and hemicellulose content within acceptable parameters for viscose grade. Table 11 presents the inorganic characteristics of the sample, showing the content of some metals. Unlike what is found in the literature, in this research extremely low values were found for the content of insoluble components in HCl.

Table 11

Elemental analysis of *Dendrocalamus asper* bleached pulp

Ashes (%)	HCl Insoluble (%)	Na (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)
0,1137	0,004	414	9,98	27,9	25,2	0,36	14,4	2,2

4. Conclusions

Due to the lower content of xylans and the higher screened yield presented after the PHK process, the species *Dendrocalamus asper* proved to be more suitable for the production of dissolving pulp than the species *Bambusa vulgaris*, reaching the viscose grade. For this, factor P equivalent to 1296, factor H equal to 802, effective alkali at 19.0% and white liquor sulfidity equal to 35.0% were used. The variation of the P factor drastically influences the degradation of hemicelluloses, so that the higher its value more efficient this compound extraction will be. Formic Acid was more efficient in the degradation of hemicelluloses when compared to Acetic Acid. There was no significant variation in the carbohydrate bleached pulp contents when compared to the brown pulp. This indicates that all hemicellulose capable of being removed was extracted before the bleaching process. The CCE step was not necessary during the bleaching process of the brown pulp. Viscosity as well as xylan content are highly influenced by the yield of purified pulp produced. During the entire process, both species did not present tailings levels, which were equivalent to 0.0%.

Further works such as the pre-hydrolysis connected to kraft pulping, reaction activities of dissolving pulp, optimization of bleaching conditions, optimization of cooking conditions and stabilization of carbohydrates chains against bleaching oxidants are necessary in order to achieve maximum efficiency of the process and adequacy to the viscose grade.

Declarations

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Figures

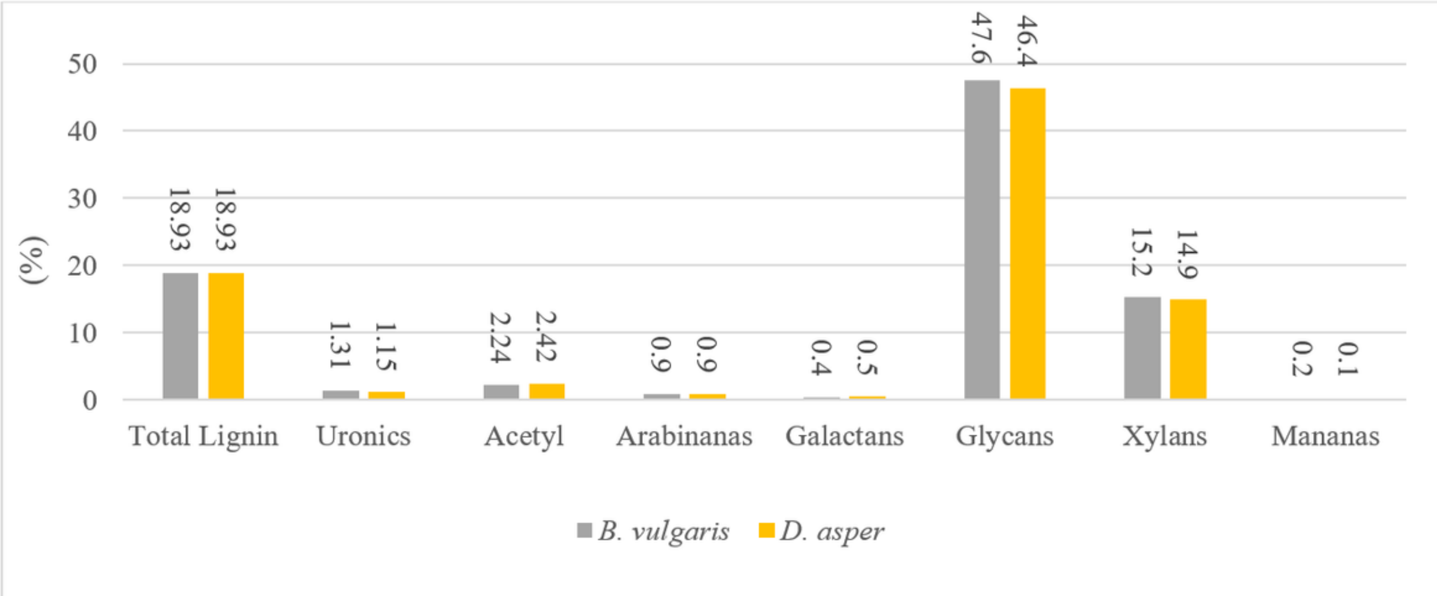

Figure 1

Bamboo chips chemical characterization

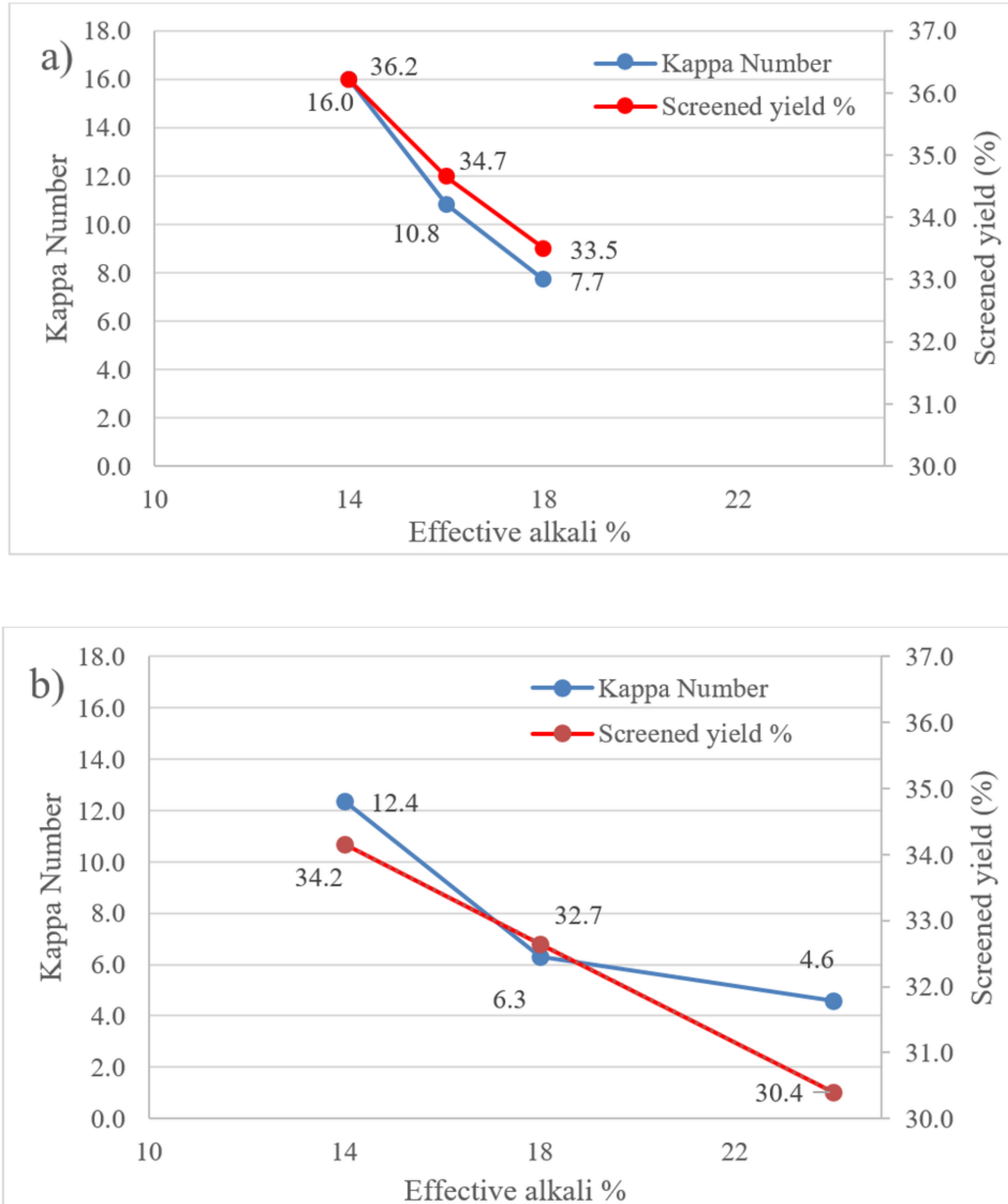

Figure 2

Effect of alkaline load variation for *Dendrocalamus asper* (a) and *Bambusa vulgaris* (b)