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COMPARATIVE STUDY BETWEEN THE CHEMI-THERMO MECHANICAL PULPING FROM *EUCALYPTUS SPP.*, *BAMBUSA VULGARIS* AND *DENDROCALAMUS ASPER*

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ABSTRACT

In this study, pulps of the species *Bambusa vulgaris* and *Dendrocalamus asper* were produced through the chemi-thermo mechanical pulping process, which had their morphological and mechanical properties compared with industrially produced *Eucalyptus spp.* pulp. The total yields of the pulping processes were 71.3 and 77.0% for the species *Bambusa vulgaris* and *Dendrocalamus asper*, respectively. The higher basic density presented by the biomass of the *Dendrocalamus asper* species can lead to a high productivity. Both bamboo species led to pulps with higher mechanical properties compared to industrial *Eucalyptus spp.* pulp. The pulp of *Bambusa vulgaris* stood out in terms of mechanical properties, reaching a higher level of mechanical properties with less energy spent on refining, being indicated for the production of papers for applications where high tensile index is required. *Dendrocalamus asper* pulp proved to be more suitable for applications, in which high liquid absorption capacity is required due to its high bulk.

KEYWORDS: CTMP, *eucalyptus spp.* x bamboo, bulk, tensile.

INTRODUCTION

The pulp industries produce different types of products, which, in turn, require different types of cellulosic pulps. Therefore, it is of great interest to include crops of other species to meet this demand (Sarto et al. 2015). The 1400 known species of bamboo, a crop of the grass family (Yeasmin et al. 2015), generate great interest as they can lead to high forest productivity (Yusuf et al. 2018). This high productivity is due to bamboo being a fast-growing plant with a short cutting cycle (Júnior et al. 2019). Furthermore, bamboo can grow in hot, very humid, and very cold environments. It also withstands altitudes ranging from sea level to 4000 m and also tolerates excessive precipitation (Yeasmin et al. 2015).

Bamboos have more than a thousand applications, ranging from food to use in supercapacitors (Liese et al. 2015, Yang et al. 2014). Among these various applications is the production of paper and pulp, especially in the Asian continent (Bhardwaj 2019). Among the various cellulose pulp production processes, the production of chemi-thermo mechanical pulping pulp (CTMP) stands out, due to the reduction in energy expenditure compared to purely mechanical processes and the high yield compared to purely chemical processes. In addition, CTMP leads to a lower environmental impact and allows, through changes in process variables, greater control of the properties of the pulp produced (Deng and Ragauskas 2012). When the objective is to use pulp for paper production, it is interesting to apply refining to change the properties of the fibers, leading, for example, to greater flexibility and greater mechanical resistance to certain types of physical effort. Thus, the refined fibers can form a paper with more favorable characteristics for the desired application (Hubbe 2014, Manfredi et al. 2012).

With all this in mind, the objective of this work was to perform a chemi-thermo mechanical pulping preceded by a cold soda process with two bamboo species, *Bambusa vulgaris* and *Dendrocalamus asper*, in order to evaluate morphological properties, refining performance, and physical resistance of pulps. The results were compared with those obtained from *Eucalyptus spp.* industrially produced. This comparison allowed to evaluate the possibility of applying these raw materials in the production of pulp and paper.

MATERIAL AND METHODS

The present study used biomass chips of *Bambusa vulgaris* and *Dendrocalamus asper* from southeast Brazil to compare with the industrial pulp of *Eucalyptus spp.* The size of the chips was controlled with length and height less than 45 mm and thickness between 2 to 4 mm according to SCAN-CM 40:01. The basic density and moisture content in the raw materials were determined according to TAPPI T 258 om-16. Each analysis was performed in duplicate.

Before the pulping process, each sample, consisting of 600 g of dry mass of chips, was soaked in a NaOH solution (3% dry wood basis) for 3 days at room temperature (20-25°C). This step was done in order to obtain a suitable impregnation process. The cooking processes were carried out in 7L MK-digesters with circulating pumps. It could be observed at Tab. 1 the main conditions for both species.

Tab. 1: Conditions of the pulping process.

Parameter	Value
Days of soaking	3
NaOH on dry biomass base applied during soaking (%)	3
NaOH on dry biomass base applied during cooking process (%)	6
NaOH liquor-to-wood ratio ($L \cdot kg^{-1}$)	4
Heating time (min)	60
Cooking time at maximum temperature (min)	30
Maximum temperature (°C)	105

After the cooking process, the first step of the chip disaggregation process was carried out in a hydrapulper. Then, to perform the separation of the fibers that remained aggregated, a laboratory disc refiner was used in which one of the discs remains static while the other rotates with a power of approximately 3.4 kW. First, a distance of 0.4 mm was maintained between the discs for 3 min, and then they were positioned 0.2 mm apart for another 2 min. Both steps in the disc refiner were carried out at room temperature. After the mechanical fibrillation, the pulp was washed and drained in a laboratory centrifuge.

The black liquor samples obtained from each cooking process had their residual alkali determined according to SCAN-N 33:94 as their kappa number, TAPPI T 236 om-13, and diffuse brightness, TAPPI T 525 om-17 of each pulp produced. The total yield was determined through the ratio between the dry weight of pulp and the dry weight of biomass.

The morphological characteristics of fibers were determined using the Valmet Fiber Image Analyzer FS5 equipment that uses ultra-HD technology and artificial intelligence to perform the morphological characterization of fibers. The results were obtained through the analysis of samples of cellulosic bamboo pulps prepared in suspension with demineralized water. Samples equivalent to 25mg of dry pulp was weighed, with the suspension having a total volume of 500mL, following the conditions required by the equipment. All tests were performed with two repetitions, considering their mean value.

The next step was to carry out the pulp refining process in a PFI mill, according to TAPPI T 248 sp-15, at 10% consistency with tests at three refining levels, 1500, 3000, and 4500 mill revolutions (500, 1000, and 2000 for *Eucalyptus spp.*), in addition to tests performed with 0 revolutions for reference. The material drainability was determined by the Schopper-Riegler method according to ISO 5267-1:1999 and after this process, the following physical-mechanical tests were performed on the hand sheets: grammage TAPPI T 410 om-19, thickness TAPPI T 551 om-18, bursting index TAPPI T 403 om-15, internal tearing resistance TAPPI T 414 om-12, resistance of paper to passage of air TAPPI T 536 om-18, tensile properties TAPPI T 494 om-13, apparent density TAPPI T 258 om-16, and specific volume also called bulk TAPPI T 220 sp-16.

RESULTS AND DISCUSSION

The basic density of *Dendrocalamus asper* was 559 kg.m^{-3} and for *Bambusa vulgaris* was 487 kg.m^{-3}. Both values are within the density range found in the literature: 485 - 737 kg.m^{-3} for *Dendrocalamus asper* (Adam and Jusoh 2019) and 473 - 592 kg.m^{-3} for *Bambusa vulgaris* (Wahab et al. 2009). The species *Dendrocalamus asper* showed a significantly higher value for basic density. This may favor productivity for a given volume of biomass in relation to *Bambusa vulgaris* (Segura and Silva Júnior 2016). However, it can also have a negative influence on chip formation and impregnation, increasing the consumption of reagents, increasing rejects, and reducing the purified yield (Cremonez et al. 2019, Queiroz et al. 2004).

The results of the pulping process of the different biomasses are presented in Tab. 3. The total yields obtained with both species were close to what is reported in the literature with soaking in soda heated at 60ºC for the species *Gigantochloa scortechinii* (Ashaari et al. 2010), with the species *Dendrocalamus asper* surpassing *Bambusa vulgaris* by almost 6%. The low values of pH and residual alkali for both species, mainly for *Bambusa vulgaris*, were necessary to maintain the level of total yield and keep lignin at the CTMP pulp (Quinde 2019). In Tab. 2, Kappa number values are presented for the pulps of each species. The high kappa number values are expected from a pulping process with a mild chemical step that removes little of the lignin.

Tab. 2: Results of the CTMP pulping process.

Parameter	*Dendrocalamus asper*	*Bambusa vulgaris*
Total yield (%)	77.0	71.3
Residual alkali of black liquor ($g \cdot L^{-1}$)	2.6	0.0
pH of black liquor	12.3	9.2
Kappa number	118	119

Tab. 3 shows the data referring to the morphological analysis of the fibers of the different pulps produced compared to *Eucalyptus spp.* pulp (Kappa number equal to 144) produced industrially. *Dendrocalamus asper* pulp presented longer fibers with greater mechanical resistance, while *Bambusa vulgaris* showed fibers slightly shorter than the previous one. Therefore, no significant variation is expected in relation to *Dendrocalamus asper* regarding this parameter. The length of *Eucalyptus spp.* fibers, as expected, was considerably shorter (about one-third) compared to the length of bamboo fibers, which leads to a loss in mechanical properties. However, shorter fibers also provide better fiber conformation in paper formation (Gomide et al. 2005, Kerekes and Schell 1995).

Tab. 3: Average morphological values for the characteristics of the studied pulps fibers.

Parameter	*Eucalyptus spp.*	*Dendrocalamus asper*	*Bambusa vulgaris*
Fiber length (mm)	0.73	2.13	2.03
Fiber width (μm)	23.60	21.32	25.72
Gravimetric coarseness ($mg \cdot m^{-1}$)	0.12	0.23	0.28
10^3 x number of fibers per mg	11.2	1.8	2.6
Fines A (%)[1]	32.9	10.3	18.6
Fines B (%)[2]	3.1	1.8	1.4
Curl (%)	6.2	6.1	9.3

[1]Length < 0.2 mm and width < 0.2 mm, [2]length > 0.2 mm and width < 10 μm.

High coarseness values are associated with papers with greater softness and porosity, which are desired characteristics in tissue papers (Benites et al. 2018). In this parameter, *Bambusa vulgaris* presented the highest value with little difference compared to *Dendrocalamus asper*; however, both exceeded at least twice the values determined for *Eucalyptus spp.* fibers. The number of fibers per mg of *Eucalyptus spp.* was 4 to 6 times the value measured for both bamboo CTMP pulps due to the higher fines content (Tab 3).

Prior to refining, the *Eucalyptus spp.* pulp had the highest SR° followed by *Bambusa vulgaris* and *Dendrocalamus asper* (Tab. 4). The poorer dewatering of the eucalyptus pulp compared to the bamboo pulps is related to the higher fines content (Tab. 3) which inhibit dewatering (Fischer et al. 2017). The increase in SR° with refining is a measure of mechanical treatment according to ISO 5267-1:1999 (Tab. 4). And, as can be seen in Tab. 4, *Eucalyptus spp.* pulp presented a higher °SR, followed by *Bambusa vulgaris* and with *Dendrocalamus* *asper* having the lowest value for this property at zero revolutions (pulp in the condition in which the morphological analysis was performed).

Tab. 4: Mechanical properties for CTMP pulp from Eucalyptus spp. and bamboos.

Parameters / Species	***Eucalyptus spp.***				***Dendrocalamus asper***				***Bambusa vulgaris***			
Energy consumption PFI mill (Wh)	0.0	9.0	16.0	32.0	0.0	24.0	45.0	64.0	0.0	23.0	42.0	64.0
°SR	19	26	32	47	9	20	50	72	13	30	68	82
Tensile index ($N \cdot m^{-1} \cdot g^{-1}$)	9.7	12.2	14.2	16.7	3.8	19.3	29.0	38.3	13.8	39.1	47.8	50.0
Bursting index ($kPa \cdot m^2 \cdot g^{-1}$)	0.12	0.15	0.21	0.25	0.04	0.80	0.91	1.03	0.35	1.59	1.76	2.92
Tear index ($mN.m^2 \cdot g^{-1}$)	1.6	1.8	1.8	2.0	3.6	6.8	6.8	5.9	11.3	10.0	8.5	6.7
Stretch (%)	0.7	0.7	0.8	0.9	0.9	1.4	1.5	1.9	1.2	2.2	2.2	2.4
Air resistance ($s \cdot (100cm^3)^{-1}$)	0.5	0.6	0.9	1.7	0.5	0.5	1.2	7.1	0.5	1.3	11.3	128.8
Apparent density ($kg \cdot m^{-3}$)	311	319	351	370	182	256	337	377	270	361	408	495
Bulk ($cm^3 \cdot g^{-1}$)	3.2	3.1	2.9	2.7	5.5	3.9	3.0	2.7	3.7	2.8	2.5	2.0
Deformation energy ($J \cdot m^{-2}$)	3.0	3.3	4.2	5.8	2.3	10.7	17.8	25.6	8.9	35.3	43.3	49.3
Modulus of elasticity ($MN.m \cdot kg^{-1}$)	2.0	2.5	2.8	3.0	0.7	2.7	3.5	3.8	2.4	4.0	4.7	4.7

Among of the CTMP pulps from different raw materials evaluated in this work, *Bambusa vulgaris* shown the most favorable mechanical properties. These characteristics are appropriated for the production of packaging paper. It was shown in Tab. 4 the main mechanical properties for CTMP pulps during PFI mill refining process for *Eucalyptus spp.* and bamboos. The higher resistance of paper to passage of air and burst index indicates a material with a greater contact surface and number of interfiber bonds, characteristics that reflect positively on the resistance of the paper that will be produced (D'Almeida 1988, Smook et al. 1990). *Bambusa vulgaris* pulp presented the highest values for these parameters, followed by *Dendrocalamus asper* pulp, while the industrial pulp of *Eucalyptus spp.* presented the lowest values. For a more detailed analysis, some of the parameters in Tab. 6 were plotted in graphs and second-order polynomial curves were fitted to the points of all graphs for each species.

Analyzing Fig. 1, it can be seen that the tensile index of *Dendrocalamus asper* and *Bambusa vulgaris* pulp varies more markedly to the increasing of energy consumption than the industrial *Eucalyptus spp.* pulp. *Dendrocalamus asper* pulp presented significantly higher bulk for the same energy consumption and °SR (Fig. 2); therefore, its pulp is suitable for applications that require higher absorbent capacity as diapers, sanitary papers and others (Choi et al. 2018, Lund et al. 2012).

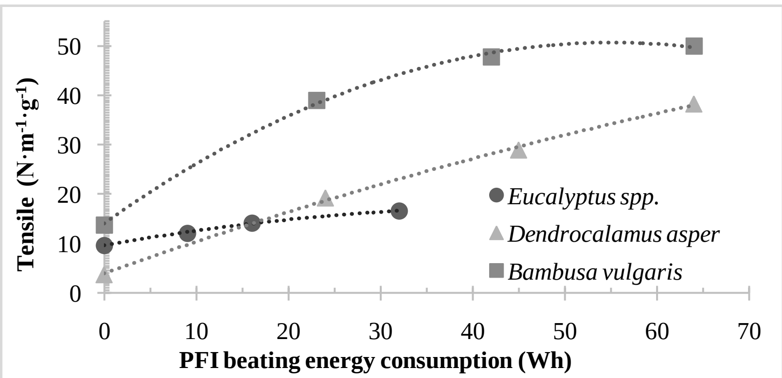

Fig. 1: Correlation between PFI beating energy consumption and tensile index from CTMP.

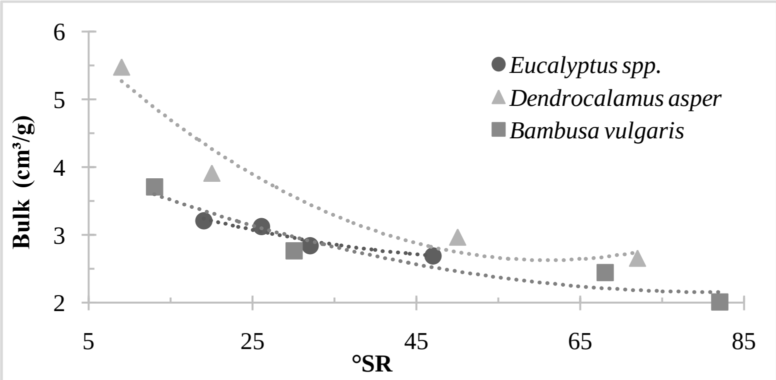

Fig. 2: Correlation between °SR and bulk from CTMP.

Fig. 3 shows that papers made with bamboo pulps had higher tensile index values than *Eucalyptus spp.* pulp. The pulp of *Bambusa vulgaris* showed higher tear (Fig. 4) and tensile index than other species indicating that it has fibers with greater resistance to such efforts; hence, it is indicated as a reinforcement fiber (Watson and Bradley 2009). *Dendrocalamus asper* showed intermediate values in the tear index parameter between the pulp of *Eucalyptus spp.* and *Bambusa vulgaris*.

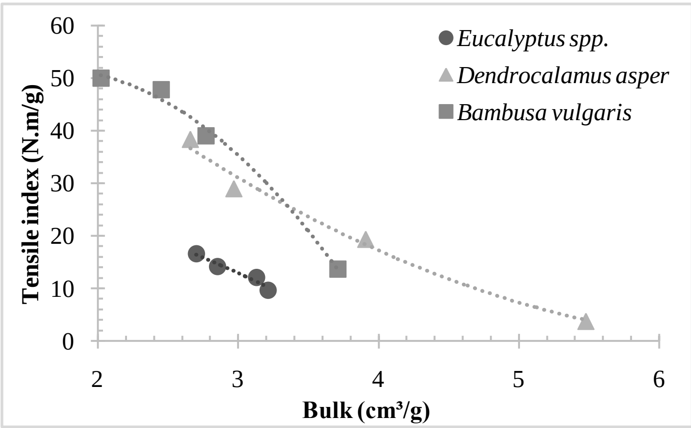

Fig. 3: Correlation between bulk and tensile index from CTMP.

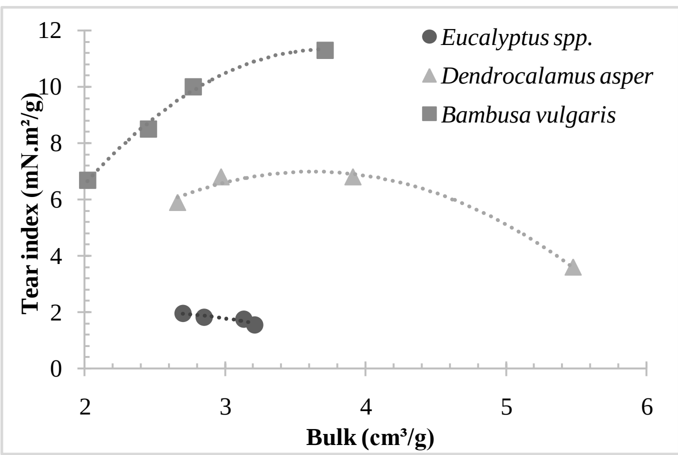

Fig. 4: Correlation between bulk and tear index from CTMP.

The tensile index and tear index properties behave differently with varying degrees of refining. Therefore, it is useful to evaluate the tensile index against the tear index to verify the optimal degree of refining aiming at the maximum value of both parameters, as shown in Fig. 5. Using the fitted curves, we find that the optimal value of tensile index for *Bambusa vulgaris* is 23 $N \cdot m \cdot g^{-1}$ (tear index 11.8 $mN \cdot m^2 \cdot g^{-1}$) and 25.6 $N \cdot m \cdot g^{-1}$ (tear index 7.0 $mN \cdot m^2 \cdot g^{-1}$) for *Dendrocalamus asper*. These values are reached after approximately 480 revolutions (7.2 Wh consumed) at the PFI mill for *Bambusa vulgaris* and 2400 revolutions (37 Wh consumed) for *Dendrocalamus asper*. That shown a big economy for energy spent to reach the optimum refining point and the superiority of *Bambusa vulgaris* pulp parameters compared to *Dendrocalamus asper* and *Eucalyptus spp.* industrial pulp. For *Eucalyptus spp.*, the variation of tear index with refining is not significant, but tensile index is substantially higher after beating process. However, bamboo CTMP shown much higher values of tear index and tensile index than *Eucalyptus spp.* pulp.

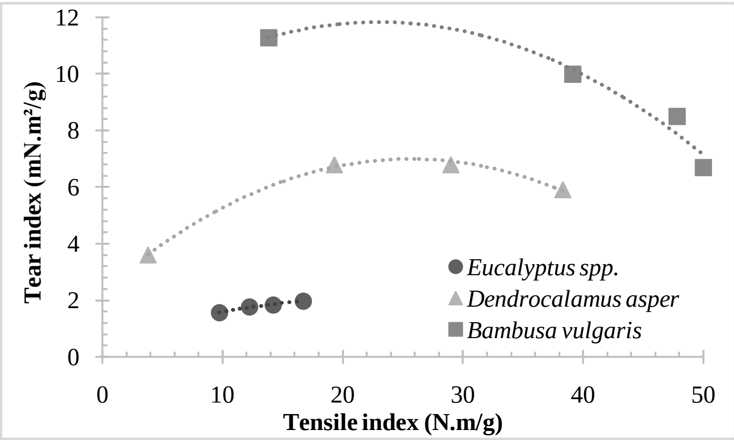

Fig. 5: Correlation between tensile index and tear index from CTMP.

CONCLUSIONS

The comparative assessment among chemi-thermo mechanical pulping from *Eucalyptus spp.*, *Bambusa vulgaris*, and *Dendrocalamus asper* aimed to evaluate the potential use of bamboo species for pulp production.

Regarding the physics properties, the basic density presented by *Dendrocalamus asper* biomass was higher than that of the other species, which can lead to higher productivity, these parameters could result in lower pulp production cash cost. Morphological analysis for bamboo CTMP pulps indicated higher fiber length, led to papers with superior mechanical properties than the paper made with the industrial pulp of *Eucalyptus spp.* CTMP *Eucalyptus spp.* pulp shown high fines content which is also in agreement with the superior value of °SR compared to bamboo species. In terms of mechanical properties, both bamboo species led to CTMP pulps with higher mechanical properties compared to industrial Eucalyptus spp. pulp.

The CTMP pulp of *Bambusa vulgaris* stood out in terms of mechanical properties, reaching a higher level of mechanical properties. In addition, shown less energy consumption in refining to achieve a certain tensile index and tear index compared to *Eucalyptus spp*. CTMP pulp. Indicating its capability for the CTMP production when high mechanical properties is required.

On the other hand, *Dendrocalamus asper* pulp proved to be more suitable for applications where high bulk is required. Bamboo CTMP pulp showed much higher tear index values, at the same tensile index than *Eucalyptus spp.* pulp, which should be related to their intrinsic fiber strength.

In conclusion, the comparative evaluation among *Eucalyptus spp.*, *Bambusa vulgaris*, and *Dendrocalamus asper* demonstrated the potential use of bamboo species for CTMP pulp production, highlighting their superior mechanical properties. Further research is needed to expand the findings of this study and assess the feasibility of using other bamboo species for pulp production. Additionally, CTMP process for bamboo, as raw material should focus on optimize the impregnation time and temperature in order to increase selectivity and yield, therefore decrease fines content.

REFERENCES

1. Adam, N., & Jusoh, I. (2019). Physical and Mechanical Properties of Dendrocalamus asper and Bambusa vulgaris. Trans. Sci. Technol, 6, 95-101.
2. Ashaari, Z., Salim, S., Halis, R., Yusof, M. N. M., & Sahri, M. H. (2010). Characteristics of pulp produced from refiner mechanical pulping of tropical bamboo (*Gigantochloa scortechinii*). *Pertanika Journal of Tropical Agricultural Science, 33*(2), 251-258.
3. Benites, P. K.R.M., da Silva Lopes, A., de Fátima Gomes Gouvêa, A., da Silva, F. C., & Borges de Souza, C. C. (2018). Caracterização tecnológica da madeira de híbridos de eucalipto irrigados e fertirrigados. *Ciência Florestal (01039954), 28*(4). (Technological characterization of irrigated and fertirrigated eucalyptus hybrid wood).
4. Bhardwaj, N. K. (2019). Refining of bamboo long fiber fraction pulp: effects on wet web and dry strength properties of paper. *Cellulose Chemistry and Technology, 53*(1-2), 113-120.
5. Choi, K.-H., Kim, A. R., & Cho, B.-U. (2018). Manufacture of high bulk paper using alkali swollen kraft pulp. *Nordic Pulp & Paper Research Journal, 33*(3), 503-511.
6. Cremonez, V. G., Bonfatti, E. A., Andrade, A. S. d., Silva, E. L. d., Klitzke, R. J., & Klock, U. (2019). Wood basic density effect of *Eucalyptus grandis* in the paper making. *Matéria (Rio de Janei*ro), 24(3).
7. D'Almeida, M. L. O. (1988). Celulose e Papel - Tecnologia de Fabricação do Papel. Instituto de Pesquisas Tecnológicas do estado de São Paulo (IPT), vol. 1, pp. 848-849. (Pulp and Paper - Paper Manufacturing Technology).
8. Deng, Y., Ragauskas, A (2012). Dry Kraft Pulping at Ambient Pressure for Cost Effective Energy Saving and Pollution Deduction. Office of Scientific and Technical Information, United States.
9. Fischer, W. J.; Mayr, M.; Spirk, S.; Reishofer, D.; Jagiello, L. A.; Schmiedt, R.; Colson, J.; Zankel, A.; Bauer, W. (2017). Pulp fines - characterization, sheet formation, and comparison to microfibrillated cellulose. *Polymers, 9*, 366.
10. Gomide, J. L., Colodette, J. L., Oliveira, R. C. d., & Silva, C. M. (2005). Technological characterization of the new generation of eucalyptus clones in Brazil for kraft pulp production. *Revista árvore, 29*, 129-137.

11. Hubbe, M. A. (2014). Prospects for Maintaining Strength of Paper and Paperboard Products While Using Less Forest Resources: A Review. *Bioresources*, 9(1).
12. Júnior, E. A. B., E. C. Lengowski, A. S. de Andrade, I. Venson, U. Klock, F. G. da Silva Júnior, J. C. Gonçalez and G. I. B. de Muñiz (2019). Bamboo kraft pulping. *Advances in Forestry Science, 6*(4), 791-796.
13. Kerekes, R. J., & Schell, C. J. (1995). Effects of fiber length and coarseness on pulp flocculation. *Tappi journal*. 78, 133-139.
14. Liese, W., Welling, J., & Tang, T. K. H. (2015). Utilization of bamboo. In W. Liese & M. Köhl (Eds.), *Bamboo: The Plant and its Uses* (pp. 299-346).
15. Lund, K., Sjöström, K., & Brelid, H. (2012). Alkali Extraction of Kraft Pulp Fibers: Influence on Fiber and Fluff Pulp Properties. *Journal of Engineered Fibers and Fabrics, 7*(2), 155892501200700206.
16. Manfredi, M., Oliveira, R. C. d., & Silva, J. C. d. (2012). Melhoramento das propriedades de papéis reciclados através da ultrassonificação das fibras e adição de xilanas. *Revista árvore, 36*, 777-785. (Development of recycled paper properties by ultrasonic treatment and addition of xylan).
17. Queiroz, S. C. S., Gomide, J. L., Colodette, J. L., & Oliveira, R. C. d. (2004). Influência da densidade básica da madeira na qualidade da polpa kraft de clones híbridos de *Eucalyptus grandis* W. Hill ex Maiden x *Eucalyptus urophylla* ST Blake. *Revista árvore, 28*, 901-909. (Effect of wood basic density on kraft pulp quality of hybrid *Eucalyptus grandis* W. Hill ex Maiden X *Eucalyptus urophylla* S.T. Blake clones).
18. Quinde, A. (2019). Residual effective alkali control maintain ideal levels in kraft pulping, from the digester to the recovery cycle. *Pulp & Paper-Canada*, *120*(3), 16-19.
19. Sarto, C., Segura, T. E. S., & da Silva Júnior, F. G. (2015). Performance of *Schizolobium amazonicum* wood in bleached kraft pulp production. *Bioresources*, *10*(3), 4026-4037.
20. Segura, T. E., & Silva Júnior, F. G. (2016). Potential of C. citriodora wood species for kraft pulp production. *Tappi Journal*, *15*(3), 159-164.
21. Smook, G. A., Pastor, J. F. C., Hortal, J. A. G., & Torres, A. L. (1990). Manual para técnicos de pulpa y papel: TAPPI Press. (Manual for pulp and paper technicians).
22. Wahab, R., Mohamed, A., Mustafa, M. T., & Hassan, A. (2009). Physical characteristics and anatomical properties of cultivated bamboo (*Bambusa vulgaris* Schrad.) culms. *Journal of Biological Sciences, 9*(7), 753-759.
23. Watson, P., & Bradley, M. (2009). Canadian pulp fibre morphology: superiority and considerations for end use potential. *The Forestry Chronicle, 85*(3), 401-408.
24. Yang, C.-S., Jang, Y. S., & Jeong, H. K. (2014). Bamboo-based activated carbon for supercapacitor applications. *Current Applied Physics, 14*(12), 1616-1620.
25. Yeasmin, L., Ali, M. N., Gantait, S., & Chakraborty, S. (2015). Bamboo: an overview on its genetic diversity and characterization. *3 Biotech*, *5*(1), 1-11.
26. Yusuf, S., Syamani, F. A., Fatriasari, W., & Subyakto. (2018). Review on bamboo utilization as biocomposites, Pulp and Bioenergy. IOP Conference Series: Earth and Environmental Science, 141, 012039.

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