

Kraft Pulp from Juvenile and Mature Woods of *Corymbia citriodora*

Elias T. D. Severo,^a Cláudio A. Sansígolo,^a Fred W. Calonego,^{a,*} and Ricardo M. Barreiros^b

Kraft pulp produced from juvenile and mature wood from thirty-two-year-old *Corymbia citriodora* trees was evaluated. The stem was subdivided into regions of juvenile and mature wood, and then it was transformed into chips. These materials were then cooked in the Laboratory of Pulp and Paper at São Paulo State University (UNESP, Botucatu, SP, Brazil) and the physico-mechanical properties of the pulps were determined. The results showed that: (1) the pulp yields of mature wood were up to 4.4% greater in comparison to the juvenile wood, (2) the juvenile wood pulp required a shorter refining time than mature wood to reach the same Schopper-Riegler degree, (3) the juvenile wood pulp presented lower specific volume, and (4) the mature wood pulp presented greater air resistance, tensile, tear and burst index values, stress-strain factor, and stretch than the juvenile wood pulp.

Keywords: Kraft pulps; *Corymbia citriodora*; Pulp properties; Juvenile wood; Mature wood

Contact information: a: Department of Forest Science, Faculty of Agricultural Sciences, UNESP, Fazenda Experimental Lageado, CEP: 18603-970, P.O. Box 237, Botucatu, SP, Brazil; b: Experimental Campus of Itapeva, UNESP, Geraldo Alckmin Street, 519, CEP: 18409-010, Itapeva, SP, Brazil;

* Corresponding author: fwcalonego@ig.com.br

INTRODUCTION

In general, the heterogeneity of wood causes a great deal of inconvenience to the manufacturing and processing industries that utilize the wood. The material's chemical and physical differences can be attributed to several factors: species, silviculture, and particularly the wood anatomy. Juvenile wood can be defined as being close to the pith, and it differs from mature wood on account of several key differences in composition and properties, among which are lignin, holocelluloses and extractives contents, specific gravity, and length and wall thickness of fibers (Bao *et al.* 2001; Calonego *et al.* 2005; Costa 1997; Ferreira *et al.* 2011; Zobel and Van Buijtenen 1989).

Nevertheless, it should be mentioned that the chemico-anatomical variations in the wood affect the production and quality of the pulp and the paper. The pulp yield of mature wood has been found to be greater in comparison to juvenile wood. Further, the paper produced from this type of wood has higher density, tensile index, and burst index, and produces smoother sheets; however, it has a smaller tear index and opacity in comparison to the mature wood (Zobel and Van Buijtenen 1989; Hatton and Cook 1992; Hatton 1997; Santos and Sansígolo 2007).

Myers *et al.* (1996) demonstrated that the kraft pulping of *Populus tremuloides* resulted in a pulp yield of 55% and a Schopper-Riegler degree of 25. The juvenile wood pulp presented sheet density, stretch, tear, and burst and tensile indexes of 0.696 g/cm³, 1.1%, 6.7 mN.m²/g, 3.2 kPa.m²/g, and 78.1 N.m/g, respectively. In mature wood pulp, the

corresponding values were 0.725 g/cm³, 1.7%, 7.6 mN.m²/g, 4.0 kPa.m²/g, and 79.2 N.m/g, respectively.

The variations in the pulp properties of juvenile and mature woods can be explained based on differences in fiber coarseness. The juvenile vs. mature fibers of *Pseudotsuga menziesii*, *Pinus banksiana*, and *Pinus contorta* had a fiber coarseness of 202 vs. 228, 196 vs. 250, and 179 vs. 226 µg/m, respectively (Hatton 1997). According to the studies of Campos *et al.* (2000), Corson *et al.* (2004), and Myers *et al.* (1996), the longer fiber lengths and greater fines content of the mature wood positively influenced the mechanical properties of the pulp.

Hatton and Gee (1994) showed that the kraft pulp of *Pinus contorta*, which was refined up to 6000 PFI revolutions, presented a Schopper-Riegler degree of less than 20, and the juvenile wood pulp presented sheet density, tensile index, and burst index significantly higher than pulp from the mature wood. When the refining level was increased to 12000 PFI revolutions, the Schopper-Riegler degree, tensile index, and burst index of juvenile wood pulp were 30, 121 N.m/g, and 10 kPa.m²/g, whereas for the pulp from mature wood those values were 32, 119 N.m/g, and 10.3 kPa.m²/g, respectively. The pulp yield and the tear index of pulp from mature wood were greater than that of juvenile wood pulp.

Costa *et al.* (1997) produced bleached pulp from *E. urophylla* x *grandis*, *Eucalyptus urophylla*, *Eucalyptus pellita*, and *Corymbia citriodora* and concluded that the last species presented advantages owing to the greatest delignification in cooking, pulp yield, α-cellulose content, viscosity, and whiteness. Nevertheless, the authors recommended the continuation of studies on pulping these woods.

Although various studies have been conducted on the juvenile and mature wood of softwoods, there is little corresponding knowledge for hardwoods (Myers *et al.* 1996; Bao *et al.* 2001). Thus, the present study is aimed at evaluating the kraft pulp from juvenile and mature woods of *Corymbia citriodora*.

EXPERIMENTAL

Collection of Material

This study utilized the wood of four trees from 32-year-old *C. citriodora* from the Forestry Institute of São Paulo located in Mandurí, São Paulo, Brazil. Trees were felled, and disks were sectioned into the stem. The first disk was sectioned to 0.30 m height, and the others each at 4.00 m, up to a minimum diameter of 12 cm. The disks were subdivided into regions of juvenile and mature wood according to Calonego *et al.* (2005), who concluded that the juvenile wood of this species is confined to approximately between 40 and 55 mm from the pith.

Subsequently, samples of the mature and juvenile woods were transformed into chips. The chips of each type of wood were grouped into samples, which represented each tree that was studied. A portion of the chips was processed into sawdust with a cutting mill. The material was classified between 40 and 60 mesh. Chemico-anatomical studies of this material were performed by Calonego *et al.* (2005) and Severo *et al.* (2006), as shown in detail in Table 1. The remaining chips were utilized for kraft pulping.

Table 1. Chemico-Anatomical Properties of Juvenile and Mature Woods from *C. citriodora**

Properties	Juvenile Wood	Mature Wood
Fiber length, mm	0.943 at 1.140	1.186 at 1.350
Extractives content, %	7.29	7.26
Klason lignin content, %	23.71	20.70
Holocellulose content, %	69.40	72.04

*According to Calonego *et al.* (2005) and Severo *et al.* (2006)

Kraft Pulping of Wood

The kraft pulping of the juvenile and mature woods of *C. citriodora* was performed in a Regmed digester. The following kraft cooking conditions were used: active alkali as Na₂O of 15% o.d. wood, 25% sulfidity, 0.05% anthraquinone, maximum cooking temperature of 170 °C, time up to target a maximum temperature of 90 min, cooking time at maximum temperature of 45 min, and liquor-to-wood ratio of 3.8 L/kg. Subsequently, the pulps were washed, screened, and processed in a Brecht Roll using a screen with 0.2 mm slots.

Refining and Physico-Mechanical Properties of Kraft Pulp

Samples of each kraft pulp were beaten in a Jökro mill at four revolution levels (3000, 6000, 9000, and 12000). The refining degree was determined by the Schopper-Riegler method (SCAN C19:65).

The handsheets were made with a Rapid-Köthen sheet former for the physico-mechanical tests, and placed in a climatic chamber adjusted to 23 ± 2 °C and 50 ± 2% relative humidity (RH), according to the standards presented in TAPPI T 402 om-03. The following physico-mechanical properties were evaluated: specific volume (TAPPI T 220 sp-96), tensile properties (TAPPI T 494 om-96), burst index (TAPPI T 403 om-97), tear index (TAPPI T 414 om-98), and air resistance (TAPPI T 460 om-96). The relationship between each physico-mechanical property and the Schopper-Riegler degree was evaluated using polynomial regression, by taking into account the observed tendency of data.

RESULTS AND DISCUSSION

Kraft Pulping of Juvenile and Mature Woods

The parameters that were used to characterize the kraft pulping of juvenile and mature wood from *C. citriodora* are shown in Table 2. It can be seen that the gross and screened pulp yield of mature wood were greater than that of juvenile wood. The reject rate wood basis and pulp basis of the material produced from mature wood were significantly smaller in comparison to the pulping of the juvenile wood. These results were similar to those presented by Hatton and Gee (1994) and Hatton (1997). The authors explain that the smallest holocelluloses content and greatest lignin content of juvenile wood, as shown in Table 1, reduces the yield and increases the rejects produced during pulping.

Table 2. Kraft Pulping of Juvenile and Mature Woods from *Corymbia citriodora*

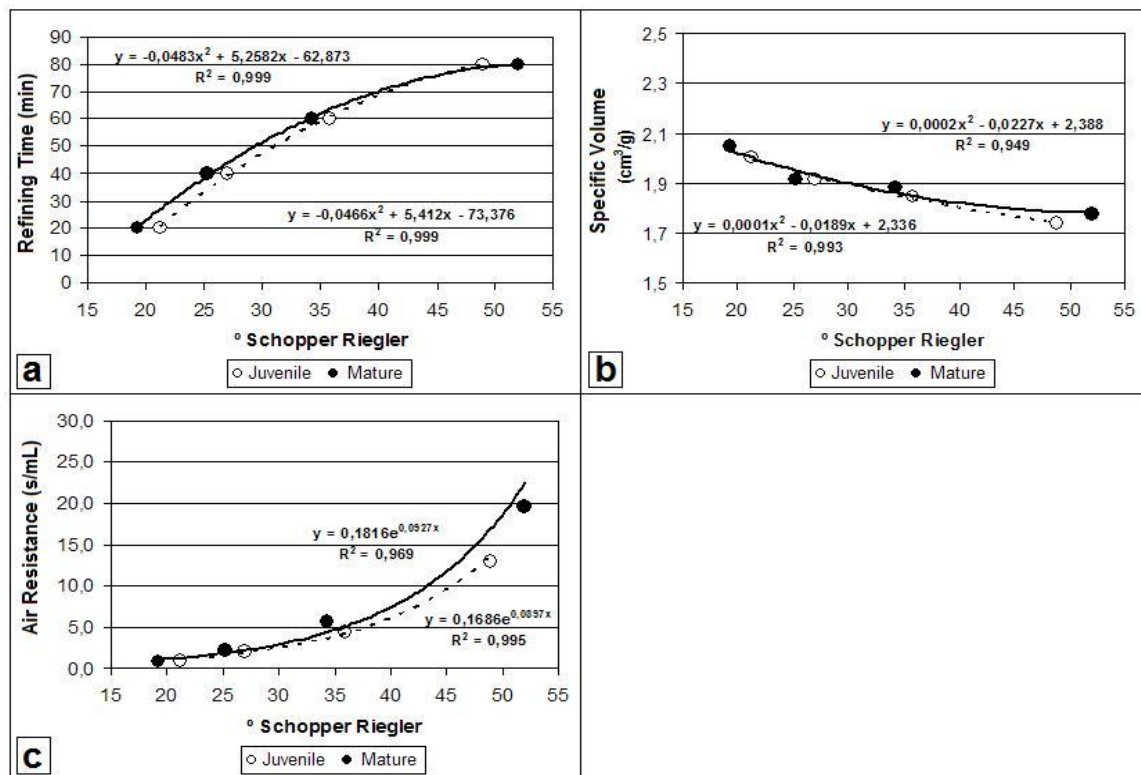
Properties	N	Juvenile wood		Mature wood		Reduction or (increase) %
		c.v.	Average	c.v.	Average	
Gross pulp yield, % o.d. wood	4	2.4	51.11	1.3	52.54	(2.8) ^{NS}
Screened pulp yield, % o.d. wood	4	2.6	49.73	1.4	51.93	(4.4) [*]
Reject rate, % o.d. wood	4	9.4	1.38	33.2	0.61	55.8 [*]
Reject rate, % o.d. pulp	4	11.0	2.71	33.7	1.16	57.2 [*]
Kappa number	4	11.5	22.43	28.4	24.50	9.2 ^{NS}

where: N - repeat number of samples; c.v. - coefficient of variation, %; * - significant difference by F test at probability 95%; NS - non-significant difference

Physico-mechanical Properties of the Kraft Pulps

The physico-mechanical properties of the kraft pulps of juvenile and mature woods from *C. citriodora* are shown in Figs. 1 and 2, in the form of the Schopper-Riegler degree.

It can be verified from Fig. 1 that the kraft pulp from juvenile wood of *C. citriodora* required a shorter refining time compared to the pulp from mature wood to reach the same Schopper-Riegler degree. These results were similar to those shown by Hatton and Gee (1994), Hatton (1997), and Santos and Sansígolo (2007) for other species.

**Fig. 1.** Physical properties and air resistance of kraft pulp from *Corymbia citriodora*

The results shown in Fig. 1 are consistent with those reported by Santos and Sansígolo (2007), in which *E. urophylla* x *grandis* wood of low basic density (0.440 g/cm^3) produced pulp with a high Schopper-Riegler degree in a shorter refining time, when compared to wood of a higher density (0.508 g/cm^3). In addition, these results also confirm the conclusions of Hatton and Gee (1994) and Hatton (1997), in which the juvenile wood pulp required only a short refining time, thereby consuming less energy and reducing the cost of paper making.

It can be seen in Fig. 1b that the kraft pulp from juvenile wood yielded sheets with a smaller specific volume than the pulp from mature wood at the greatest refining levels. Similar results were reported by Hatton and Gee (1994) and Santos and Sansígolo (2007) for pulps of *Pinus contorta* and *E. urophylla* x *grandis*, respectively. Hatton and Cook (1992), Hatton and Gee (1994), Hatton (1997), and Santos and Sansígolo (2007) explained that the juvenile wood fibers has smaller coarseness, thereby producing pulps with greater consolidation among the fibers.

It can be verified from Fig. 1c that the juvenile wood pulp of *C. citriodora* presented air resistance similar to that of mature wood pulp when refined to reach 30 °SR. Additionally, the mature wood pulp showed a significant increase in air resistance with an increase in the Schopper-Riegler degree. These results were similar to those presented by Campos *et al.* (2000) and Santos and Sansígolo (2007). The higher density of the mature wood pulp with an increase of the Schopper-Riegler degree can be associated with higher fines fractions produced at the highest levels of refining. At low levels of refining, the good air resistance of the juvenile wood pulp can be explained by extensive interfiber bonding. This bonding is due to the lesser coarseness of these fibers (Hatton and Cook 1992; Hatton and Gee 1994; Hatton 1997; Bao *et al.* 2001).

Figure 2 shows that the mature wood of *C. citriodora* resulted in kraft pulp with greater stretch, tensile index, tear index, burst index, and stress-strain factor resistance compared to juvenile wood for all levels of the Schopper-Riegler degree. These results are similar to those reported by Myers *et al.* (1996) and Santos and Sansígolo (2007), in which *Populus tremuloides* and *E. urophylla* x *grandis* with the highest basic densities produced kraft pulps with greater mechanical resistance than woods with lower basic densities. The authors explained that the additional fines fractions and the greater fiber length of mature wood increased the quality of the mature pulp. In addition, similar results were obtained by Hatton and Gee (1994), in which unbleached pulp made with mature wood of *Pinus contorta* presented a tear index greater than juvenile wood. Further, this pulp, when beaten up to 6000 revolutions, exhibited tensile and burst indexes greater than the pulp made with mature wood.

Although the lesser fiber coarseness of juvenile wood improved the interfiber bonding (Hatton and Cook 1992; Hatton and Gee 1994; Hatton 1997; Bao *et al.* 2001), an increase in the refining level produced a greater proportion of fines fractions in mature wood, and the mechanical properties of this pulp would be similar or superior to those presented by the juvenile wood pulp (Campos *et al.* 2000; Corson *et al.* 2004).

The higher hemicelluloses content of mature wood can also be expected to contribute to an increase in the mechanical strength of this pulp. Hemicelluloses tend to make the fibers more easily refined, resulting in greater fibrillation rather than cutting, which increases the bonding between the fibrous elements (Campos *et al.* 2000; Santos and Sansígolo 2007).

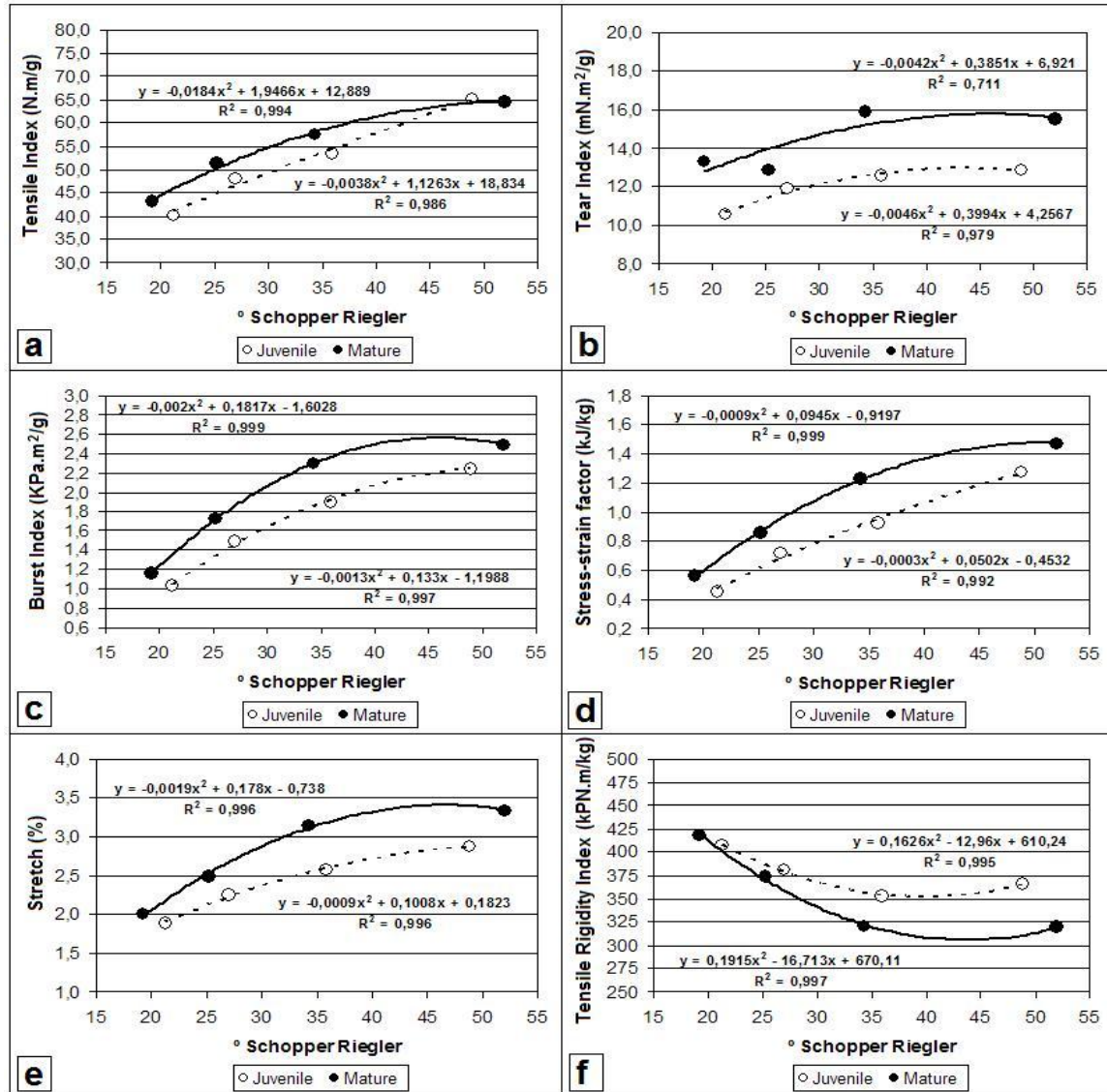


Fig. 2. Mechanical properties of kraft pulp from *Corymbia citriodora*

It can be seen from Figure 2f that the juvenile wood of *C. citriodora* yielded kraft pulp with greater tensile rigidity index compared to mature wood for all levels of the Schopper-Riegler degree.

In general, the pulps that produce paper with greater tensile strength (Figure 2a) also produce stiffer sheets. However, as previously discussed, the interfiber bonding, the chemical properties, and the refining time can change these relationships.

The tensile rigidity index is tensile stiffness divided by grammage. Tensile stiffness is numerically equivalent to $E \cdot t$, where “ E ” is modulus of elasticity and “ t ” is sheet thickness (TAPPI T 494 om-96).

As the juvenile wood fibers of *C. citriodora* have smaller coarseness, it thereby tends to result in pulps with relatively high inter-fiber bonding, and therefore with greater modulus of elasticity and tensile rigidity index compared to pulp from mature wood.

As previously shown, the kraft pulp from juvenile wood of *C. citriodora* requires a shorter refining time compared to the pulp from mature wood to reach the same Schopper-Riegler degree. The increase in the refining time causes increases in the

interfiber bonding and in the modulus of elasticity, it also reduces the sheet thickness. Therefore the tensile rigidity index of this pulp will be smaller in comparison to sheets from juvenile wood pulp.

CONCLUSIONS

1. The pulp yields of mature *Corymbia citriodora* wood were up to 4.4% greater than pulp yields from juvenile wood.
2. The juvenile wood pulp required a shorter refining time than the pulping of mature wood to reach the same Schopper-Riegler degree.
3. The juvenile wood pulp presented a lower specific volume at a given value of refining time, in comparison to mature wood.
4. The mature wood pulp presented greater air resistance, tensile index, tear index, burst index, stress-strain factor, and stretch.

REFERENCES CITED

- Bao, F. C., Jiang, Z. H., Jiang, X. M., Lu, X. X., Luo, X. Q., and Zhang, S. Y. (2001). "Differences in wood properties between juvenile wood and mature wood in 10 species grown in China," *Wood Sci. Technol.* 35(4), 363-375.
- Calonego, F. W., Severo, E. T. D., and Assi, P. P. (2005). "Fiber length measurement for the determination of juvenile wood in *Eucalyptus citriodora*," *Sci. For.* 68, 113-121.
- Corson, S. R., Flowers, A. G., Morgan, D. G., and Richardson, J. D. (2004). "Paper structure and printability as controlled by the fibrous elements," *Tappi J.* 3(6), 14-18.
- Costa, M. M., Colodette, J. L., Gomide, J. L., and Foelkel, C. E. B. (1997). "Avaliação preliminar do potencial de quatro madeiras de eucalipto na produção de polpa solúvel branqueada pela sequencia OA(ZQ)P," *Rev. Árvore* 21(3), 385-392.
- Campos, E. S., Martins, M. A. L., Foelkel, C. E. B., and Frizzo, S. M. B. (2000). "Seleção de critérios para a especificação de pastas celulósicas branqueadas de eucaliptos na fabricação de papéis para impressão 'offset'," *Cienc. Florest.* 10, 57-75.
- Ferreira, A. L., Severo, E. T. D., and Calonego, F. W. (2011). "Determination of fiber length and juvenile and mature wood zones from *Hevea brasiliensis* trees grown in Brazil," *Eur. J. Wood. Prod. / Holz Roh-Werkst.* 69(4), 659-662.
- Hatton, J. V., and Cook, J. (1992). "Kraft pulps from second-growth Douglas fir: Relationships between wood, fiber, pulp, and handsheet properties," *Tappi J.* 75, 137-144.
- Hatton, J. V., and Gee, W. Y. (1994). "Kraft pulping of second-growth lodgepole pine," *Tappi J.* 77(6), 91-102.
- Hatton, J. V. (1997). "Pulping and papermaking properties of managed second-growth softwoods," *Tappi J.* 80(1), 178-184.
- Myers, G. C., Arola, R. A., Horn, R. A., and Wegner, T. H. (1996) "Chemical and mechanical pulping of aspen chunkwood, mature wood, and juvenile wood," *Tappi J.* 79(12), 161-168.

Santos, S. R., and Sansígolo, C. A. (2007). “Influência da densidade básica da madeira de clones de *Eucalyptus grandis* x *urophylla* na qualidade da polpa branqueada,” *Cienc. Florest.* 17(1), 53-63.

SCAN Standard 1980, C19:65

Severo, E. T. D., Calonego, F. W., and Sansígolo, C. A. (2006). “Composição química da madeira de *Eucalyptus citriodora* em função das direções estruturais,” *Silva Lusitana* 14(1), 113-126.

TAPPI Standard 1999, T220 sp-96

TAPPI Standard 1999, T402 om-03

TAPPI Standard 1999, T403 om-97

TAPPI Standard 1999, T414 om-98

TAPPI Standard 1999, T460 om-96

TAPPI Standard 1999, T494 om-96

Zobel, B. J., and Van Buijtenen, J. P. (1989). *Wood Variation: Its Causes and Control*, Springer-Verlag, New York.

Article submitted: November 05, 2012; Peer review completed: January 4, 2013; Revised version received and accepted: January 30, 2013; Published: February 7, 2013.