WITHIN-TREE VARIATION OF HEARTWOOD, EXTRACTIVES AND WOOD DENSITY IN THE EUCALYPT HYBRID UROGRANDIS (*EUCALYPTUS GRANDIS* × *E. UROPHYLLA*)

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ABSTRACT

The within-tree variation of heartwood content and the accumulation of extractives were studied in the eucalypt hybrid urograndis (*Eucalyptus grandis* × *E. urophylla*) in five 5.6-year-old trees from one clone in a commercial pulpwood plantation in Brazil. Wood basic density was on average 0.491 g/cm^{-3} and with a small axial variation. Heartwood was present in all the trees up to 65% of total tree height, amounting to 38.8% of the total volume. Within the tree, heartwood decreased from the base upwards, on average representing 51%, 44%, 39%, 32%, and 19% of cross-sectional area at, respectively, 5%, 25%, 35%, 55%, and 65% of total tree height, with a very small between-tree variation. The extractives content of heartwood was double that of sapwood (7.6% vs. 3.7%). The extractives were mostly ethanol and water solubles that showed a trend of decreasing content along the stem from base upwards. Heartwood is a quantitative significant quality parameter in the wood of the urograndis eucalypt hybrid, and its inclusion in selection programs is suggested.

Keywords: Heartwood, extractives, wood density, eucalypt hybrid, urograndis, *Eucalyptus grandis* × *E. urophylla.*

INTRODUCTION

Some eucalypts have become increasingly important pulpwood species in different parts of the world, i.e., southern Europe, South America, South Africa, and Australia. Examples are *Eucalyptus globulus* and *E. grandis,* which combine fast growth with excellent wood quality for pulp and paper production. Species crossings have also been made, and today hybrids are used extensively in commercial plantations, mostly as clonal forestry, for instance in Congo and in Brazil.

The so-called urograndis hybrid (*E. grandis*

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× *E. urophylla*) in Brazil provides a significant share of the world's eucalypt pulpwood supply, covering approximately 400,000 ha. The pulp company Aracruz developed the hybrid, aiming at combining the wood quality of *E. grandis* with the higher canker resistance and wood density of *E. urophylla.* At present the company owns about 150,000 ha of clonal urograndis plantations. High productivities are obtained in short cycles of 6 years, which attain average yields of 12 tons/ha^{-1}/yr^{-1}.

Very little is known about the heartwood development in the trees of such young hardwood plantations, in spite of the disadvantageous behavior of heartwood in pulping. Heartwood causes higher chemical consumption, lower pulp yield and brightness, mostly derived from the accumulation of extractives that accompanies heartwood formation (Higgins 1984).

Heartwood content relates to tree age. In *Eucalyptus* the formation of heartwood has been reported to start at 5 to 8 years of tree age (Hillis 1962, 1972, 1987). Recently it was shown that in plantation-grown *E. globulus* at 9 years of age, heartwood represented 17–30% of the total tree volume, depending on site, being present up to ca. 60–75% of the total tree height (Gominho and Pereira 2000). Heartwood has been reported as positively correlated to tree growth in *E. grandis* (Bamber and Fukazawa 1985) and in *E. globulus* (Gominho and Pereira 2000).

This paper reports on a study of the within-tree variation of heartwood and extractives content, as well as of wood density, for one clone of the urograndis eucalypt hybrid.

MATERIAL AND METHODS

The eucalypt hybrid urograndis (*Eucalyptus grandis* × *E. urophylla*) growing in a plantation from Aracruz Celulose S.A., in Brazil, was examined in this study. The plantation Caravelas is located in Aparaju, State of Espírito Santo, at 19°30′59″S, 40°09′45″W, at 60-m altitude. The climate is dry subhumid without water deficit or excess, and the soil is a sandy yellow latosol. The plantation was established with rooted cuttings planted at 3 × 3-m spacing, and the average calculated productivity of the plantation is 37.5 m^3/ha^{-1}/yr^{-1}.

One clone (nr. 2277) was used, and five trees were randomly selected and harvested at 5 years and 7 months of age. Within-tree sampling consisted of cross-sectional discs taken at different height levels: 5%, 25%, 35%, 55%, 65%, and 90% of total tree height. The upper level corresponded to the limit of the merchantable bole.

The heartwood in the eucalypt urograndis has a distinctive reddish color, which is visually distinguishable from the light-brown sapwood. Thus, the heartwood delimitation was marked on each disc by visual observation after water impregnation. The total disc, the heartwood and sapwood areas were measured using an image analysis system (Gominho and Pereira 2000).

The wood density was determined gravimetrically as basic density after water immersion.

Extractives were determined by soxhlet extraction successively with dichloromethane (6 h), ethanol (16 h), and water (24 h). The samples for extraction were prepared as follows: each disc was cut in half, one half disc was milled, the other was separated into the heartwood and sapwood fractions, which were milled separately. The 40–60 mesh granulometric fraction was used for analysis.

The tree volume and the heartwood volume were calculated by sections corresponding to the different height levels of sampling, as a cylinder (0–5%), as conical sections (5–25%, . . ., 65%–90%), and as a cone (90%–top) using the following equations, respectively:

$$V = s_0 \times h$$

$$V = \frac{h}{3}(s_a + s_b + \sqrt{s_a \times s_b}) \quad \text{and}$$

$$V = \frac{1}{3}s_c \times h \qquad (1)$$

where s_0 = area at 5% height level; s_a = area

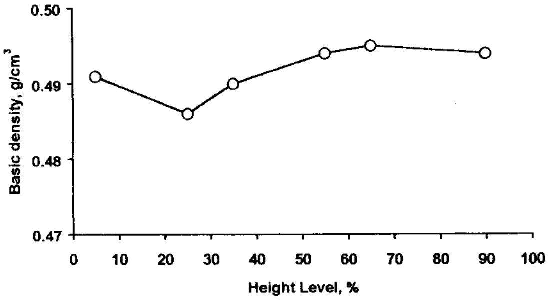

FIG. 1. Average variation of the wood basic density at different height levels within the stem of one urograndis eucalypt clone based on five trees.

at the lower height level; s_b = area at the higher height level; s_c = area at 90%; h = height of the section. The sapwood volume was calculated by difference.

Average tree wood density was calculated as a volume weighted average using the volume fraction for each section and the corresponding disc wood density (5% disc for the bottom section, 90% disc for the top section, and the average of the lower and upper discs for the other sections).

The total amount of extractives in one tree was calculated using the heartwood and sapwood volumes for each section and the corresponding content of extractives.

RESULTS AND DISCUSSION

The harvested eucalypt urograndis trees averaged 37.1 (±2.2) cm in over-bark diameter at breast height and 17.8 (±1.2) m in total height. Bark thickness averaged 5.4 (±0.5) mm and wood volume 0.097 (±0.021) m^3 per tree.

Wood density

The tree average wood basic density was 0.491 (±0.004) g/cm^{-3}. The between-tree variability was small, with coefficients of variation of the mean at all height levels under 1%. The height level was a highly significant factor of variation ($P < 0.001$). However, the variation within the tree (Fig. 1) was small, with a slight decrease to the 25% height level and a smooth increase upwards. This is a general trend in eucalypts where basic density commonly increases with height, sometimes after an initial decline (Wilkes 1988). The same axial variation of wood density has been reported for *E. grandis* with a decrease from stump to the 25% level and a gradual increase towards the top (Bhat et al. 1990).

Heartwood content

The within-tree variation of heartwood and sapwood is given in Table 1. Heartwood was present in all trees up to 65% of total tree height. Within the tree, the heartwood area at each height level decreased always from base upwards. The sapwood area also decreased from the bottom to the top, but the axial variation was smaller than for heartwood. Therefore, the percent of heartwood in the total cross-sectional area decreased with tree height from 51% at the base to 18% at the 65% height level.

The within-tree pattern of heartwood content in the urograndis hybrid was in general similar to reports on the axial development of heartwood in 9.5-year-old *E. grandis* (Wilkins

TABLE 1. *Average heartwood and sapwood cross-sectional areas, heartwood percent of total area and heartwood : sapwood ratio at different height levels within the stem of one urograndis eucalypt clone based on 5 trees (standard deviation in parentheses).*

Height level % of total	Sapwood area, cm^2	Heartwood area, cm^2	Heartwood % total area	Heartwood : sapwood
5	51.11 (6.59)	52.79 (4.05)	51.1 (3.8)	1.062 (0.171)
25	42.79 (4.20)	34.12 (3.76)	44.3 (1.8)	0.799 (0.058)
35	40.80 (3.60)	26.57 (3.34)	39.3 (1.6)	0.649 (0.044)
55	33.93 (2.78)	15.72 (2.16)	31.6 (1.6)	0.462 (0.034)
65	32.50 (3.53)	7.40 (2.10)	18.3 (3.3)	0.226 (0.048)
90	18.53 (2.54)	—	—	—

1991) and in 9-year-old *E. globulus* (Gominho and Pereira 2000).

The between-tree variation of heartwood and sapwood areas was small, with coefficients of variation of the mean around 10%, reflecting the homogeneity of the clonal material grown in the same environment. In previous studies using *E. globulus* trees of seedling origin, the between-tree variability within a site was a highly significant factor of variation (Gominho and Pereira 2000).

The extent of heartwood development in the urograndis eucalypt was larger than in 9-year-old *E. globulus* trees. For instance, at the 5% height level, heartwood represented 51% of the cross-sectional area in the 5.6-year-old urograndis hybrid and 43% in 9-year-old *E. globulus*. This means that the age of heartwood formation in the urograndis eucalypts must be less than 5 years, therefore lower than the 5–8 years reported for the beginning of heartwood formation in *Eucalyptus* species by Hillis (1972, 1987) and in accordance with estimates of about 4 years in *E. globulus* by Gominho and Pereira (2000).

The total heartwood volume was 0.037 m^3 per tree, corresponding to 38.8% of total tree volume. This again represents a greater formation of heartwood in the urograndis hybrid in comparison with 9-year-old *E. globulus*, where heartwood amounted on average to only 25% of the tree volume (Gominho and Pereira 2000). It is noteworthy that the percentage of heartwood in relation to tree volume showed in that case a high between-tree variability, with values ranging approximately 5% to 45%, which was not the case here, where very similar values were found for the five trees sampled. These results again point to the within-clone homogeneity in relation to heartwood formation.

Extractives content

The variation of total extractives within the tree is shown in Table 2 for the total wood and separately for the heartwood and sapwood fractions. The extractives in sapwood represent on average 3.7% and in heartwood 7.6%.

TABLE 2. *Average variation of total extractives in heartwood, sapwood and total wood at different height levels within the stem of one urograndis eucalypt clone based on 5 trees (standard deviation in parentheses).*

Height level % total	Heartwood	% o.d. weight Sapwood	Total wood
5	8.99 (0.72)	4.64 (0.68)	6.96 (0.74)
25	8.01 (1.12)	3.71 (0.36)	5.68 (0.53)
35	6.60 (1.28)	3.15 (0.55)	4.56 (0.75)
55	6.11 (1.11)	3.03 (0.56)	3.94 (0.69)
65	6.15 (0.75)	2.69 (0.53)	3.48 (0.33)
90	—	3.64 (0.64)	3.64 (0.64)
Average*	7.64 (0.97)	3.73 (0.35)	4.86 (0.53)

* volume weighted average.

The content of extractives decreases from the base to the top both in heartwood and in sapwood. The between-tree variation of extractives is higher than that obtained for the heartwood parameters, but the coefficient of variation of the mean remains always under 20%. The ratio of heartwood to sapwood extractives is constant at all height levels, being on average 2:1.

The determination of extractives in the total wood samples gives intermediate results following the different proportions of heartwood. If the content of extractives in the whole disc is calculated by using the values determined for the content of extractives in heartwood and sapwood (Table 2) and the proportion of heartwood and sapwood (Table 1), the values obtained are very similar to those found by the direct determination: 6.8%, 5.6%, 4.5%, 4.0%, and 3.3%, respectively, for the different height levels. This confirms that it is the varying content of heartwood that determines the accumulation of extractives in the tree.

The distribution of extractives by solvent is shown on Fig. 2 for heartwood and sapwood. The non-polar extractives solubilized in dichloromethane average 0.69% and 0.34%, respectively, in heartwood and sapwood. The major part of extractives is made up of ethanol solubles (3.99% and 1.82% in heartwood and sapwood) and water solubles (2.48% and 1.30%). Except for the dichloromethane solubles, which show little axial variation in the

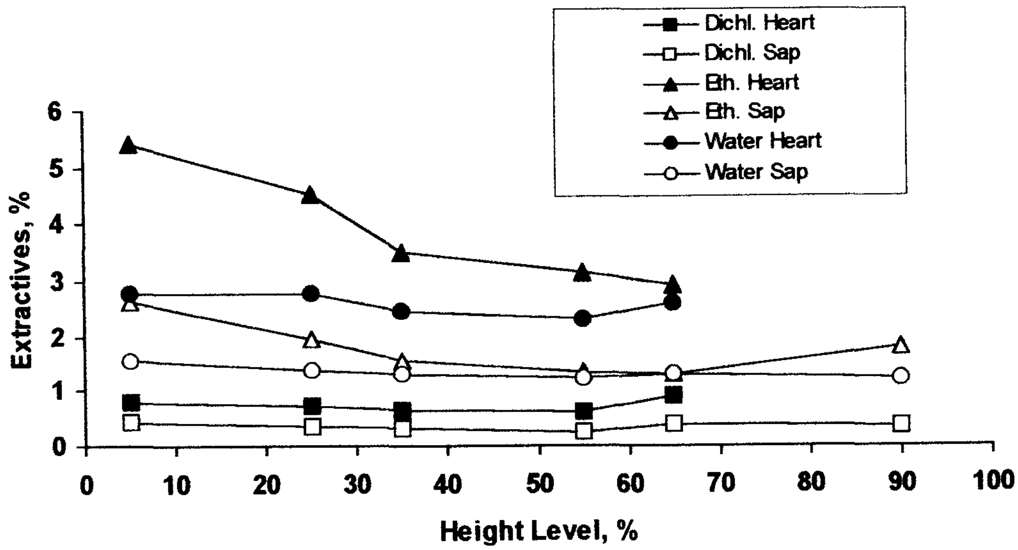

FIG. 2. Average variation of dichloromethane, ethanol and water extractives in heartwood and sapwood at different height levels within the stem of one urograndis eucalypt clone based on five trees.

tree, the ethanol and water solubles decrease along the stem from the base upwards.

On average, one tree corresponded to 47.6 kg of wood, of which 2.5 kg are extractives (1.4 kg in heartwood and 1.1 kg in sapwood).

The results of this study show the importance of heartwood accumulation in young urograndis eucalypt hybrid plantation trees, and of its content of extractives, which is double that of sapwood. Both factors negatively impact pulping quality, the effects being in direct relation to extractive accumulation (Higgins 1984). Therefore, further studies should be made on the clonal variability of heartwood formation in this urograndis hybrid in order to select clones with a low heartwood and extractives content. In fact, the natural variability that was shown to occur in *E. globulus* (Gominho and Pereira 2000) suggests the potential of a genetic selection that includes heartwood content as a quality parameter.

CONCLUSIONS

Heartwood was found in the 5.6-year-old urograndis eucalypt hybrid (*Eucalyptus grandis* × *E. urophylla*) up to 65% of total tree height and amounted to nearly 40% of the tree volume. Within the tree, heartwood decreased from the base upwards with a very small between-tree variation. The content in extractives of heartwood was the double that of sapwood. Heartwood is a quantitative significant quality parameter in the wood of the urograndis eucalypt hybrid, and its inclusion in selection programs is suggested.

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