WITHIN-TREE VARIATION IN WOOD FIBRE BIOMETRY AND BASIC DENSITY OF THE UROGRANDIS EUCALYPT HYBRID 
(EUCALYPTUS GRANDIS × E. UROPHYLLA)

Teresa Quilhó, Isabel Miranda and Helena Pereira

SUMMARY

Within-tree variations in fibre length, width, wall thickness and wood basic density of Eucalyptus grandis × E. urophylla (urograndis) were studied in five 6.8-yr-old seedling trees and five 5.6-yr-old trees from one clone from Brazil. Samples were taken at 5%, 25%, 35%, 55%, 65% and 90% of stem height and five radial positions (10%, 30%, 50%, 70% and 90% of radius). The tree average fibre length, width and wall thickness were in seed and clone trees: 0.955 mm and 1.064 mm, 18 μm and 20 μm, 3.6 μm and 4.4 μm respectively. The axial variation of fibre dimensions was very low, while there was a consistent but small increasing trend from pith to periphery. The basic density ranged from 397–464 kg/m³ to 486–495 kg/m³ respectively in seedling and clone trees with a low variation along the stem. In comparison with other eucalypt pulpwood, e.g. E. globulus, the urograndis hybrid showed similar fibre dimensions and lower basic density. Overall the within-tree variation of these wood properties was low and age had a small impact on the variation of density and fibre dimensions.

Key words: Eucalyptus grandis × E. urophylla, fibre length, fibre width, cell wall thickness, basic density, axial and radial variation.

INTRODUCTION

Some fast growing Eucalyptus species, i.e. E. globulus Labill., E. grandis W. Hill ex Maida. and E. urophylla S.T. Blake are planted on a large scale in tropical, subtropical and temperate locations where they grow with high productivity. In several countries, especially in Brazil and Congo, E. grandis and E. urophylla are also utilized as parent species to produce E. grandis × E. urophylla hybrids known commercially as urograndis eucalyps (Gouma et al. 2000) which are directed mostly to the pulp industry.

These eucalypt species have been improved through selection made for growth as well as for some pulpwood quality traits such as density and fibre characteristics. The basic density is normally the first wood property to be assessed in a tree improvement

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program (Lima et al. 2000) and in *Eucalyptus* it is under strong genetic control (Raymond 1995). The general anatomy of *Eucalyptus* has been described (Wilkes 1984; Bamber 1985) and the fibre biometry of important pulpwood species such as *E. globulus* investigated by several authors (Jorge et al. 2000; Miranda et al. 2001a, 2003; Ona et al. 2001; Rao et al. 2002; Oshima et al. 2003), who observed that provenance and site were significant sources of variation for fibre morphology although with a small within- and between-tree variation. They have suggested that cell biometry should be included in breeding programmes.

Several studies have reported on the variation of basic density and fibre characteristics in *E. grandis* and *E. urophylla* (Bhat et al. 1990; Malan & Hoon 1992; Lima et al. 2000) but as regards their hybrid urograndis there are very few publications in the international literature on its wood anatomy and density (Bouvet & Baillères 1995; Gominho et al. 2001; Carvalho & Nahuz 2001) and some of the information is of difficult access (Grzeskowski et al. 2000; Padovan et al. 2001; Bassa 2002). The species crossing aims at combining the growth characteristics of *E. grandis* with an increase in wood density and fibre physical properties given by *E. urophylla*. The assessment of these properties in the commercial hybrids used by the pulp industry is therefore one key factor to evaluate their success as a pulpwood resource. This also includes an evaluation on within- and between-tree variation as important to know the degree of homogeneity of the raw material delivered to the industry, and to estimate the impact of harvest age.

This paper gives information on the within- and between-tree variation of fibre characteristics and wood basic density of the eucalypt hybrid urograndis (*Eucalyptus grandis* × *E. urophylla*) measured in trees of seed and clone origin grown in Brazil at harvest age for the pulp industry. In tropical and subtropical regions the harvest age of the eucalypt trees for pulping is approximately 6 to 7 years, as was the case here, while in temperate climates the harvest range is approximately 9–13 years.

**MATERIAL AND METHODS**

The *Eucalyptus grandis* × *E. urophylla* trees used in this study were grown at the pulpwood “Caravelas” plantation of Aracruz Celulose S.A., in Brazil, located in Aparaju, State of Espirito Santo (19° 30’ 59” S, 40° 09’ 45” W, at 60 m). The climate is dry subhumid without water deficit or excess, and the soil is a sandy yellow latosol. The plantation was established using seedlings and clones at a 3 × 3 m spacing. One seed source (AR8) and one clone (2277) were used, and five trees of each group were randomly selected and harvested at 6.8 years and 5.6 years, respectively. Mean tree total height and diameter (at breast height) were respectively 20.0 m and 14.9 cm for the seed trees, and 17.8 m and 11.5 cm for the clone trees.

Stem sectional discs were taken from each tree at different levels of total height (5%, 25%, 35%, 55%, 65% and 90%). The radial variation was studied by sampling in each wood disc at 5 positions of radius from pith to bark (10%, 30%, 50%, 70% and 90%).

The basic density of wood was calculated using water displacement for green volume determination.
Fibre length, width and wall thickness were measured in wood samples macerated with a 1:1 solution of glacial acetic acid and hydrogen peroxide solution. The fibres were stained with astra blue. Two slides with 20 fibres per slide were measured for each sampling position with a Leitz ASM 68K semi-automatic image analyser.

At each tree height level, the mean wood fibre length, width and wall thickness were calculated as an area weighted average using the measurements at the different radial positions (Jorge et al. 2000). The tree mean fibre length, width and wall thickness were determined for each tree using a volume weighted average of the values at each height level (Jorge et al. 2000). The tree volume was calculated from sections corresponding to the different height levels of sampling as a cylinder (0–5% of total height), as conical sections (5–25%, 25–35%, 35–55%, 55–65%, 65–90%); the portion above 90% (with a diameter under 3 cm) was disregarded.

Analysis of variance was used to determine statistically significant differences at a 0.05 significance level for the different variables (fibre length, width and wall thickness, and basic density) within the tree between radial positions and between height levels, and between seed and clone trees.

RESULTS AND DISCUSSION

Table 1 shows the tree averages for fibre length, width and wall thickness, and for basic density of the wood of the eucalypt hybrid urograndis (E. grandis × E. urophylla) trees from seed and one clone. Although no major differences were found between the two tree groups, the clone trees had longer, wider and thicker fibres, and denser wood than the seed trees. For the characteristics measured the between-tree variability was small, especially in the clone trees.

Table 1. Fibre length, width, wall thickness, and basic density of the eucalypt hybrid urograndis (Eucalyptus grandis × E. urophylla) of seed and clone calculated as tree weighted average. Mean of 5 trees and standard deviation in brackets.

<table>
<thead>
<tr>
<th></th>
<th>Fibre length (mm)</th>
<th>Fibre width (μm)</th>
<th>Fibre wall thickness (μm)</th>
<th>Basic density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed</td>
<td>0.955 (0.083)</td>
<td>18.0 (0.5)</td>
<td>3.6 (0.2)</td>
<td>424 (32)</td>
</tr>
<tr>
<td>Clone</td>
<td>1.064 (0.040)</td>
<td>20.0 (1.0)</td>
<td>4.4 (0.3)</td>
<td>491 (1)</td>
</tr>
</tbody>
</table>

The axial variation of fibre length, width and wall thickness in seed and clone trees are shown in Figure 1 and Table 2, and the pith to periphery variation is shown in Figures 2, 4 and 5.
Fibre length

The tree average fibre length ranged from 0.824–1.035 mm and 1.009–1.108 mm respectively in the seed and clone trees. The between-tree variability was very small corresponding to a coefficient of variation of the mean of 9% and 4%, respectively, in the seed material and in the clone trees.

Table 2. Variation of fibre width and wall thickness of the eucalypt hybrid urograndis (Eucalyptus grandis × E. urophylla) of seed and clone. Mean of 5 trees and standard deviation in brackets.

<table>
<thead>
<tr>
<th>Stem height position (%)</th>
<th>Fibre width (µm)</th>
<th>Fibre wall thickness (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seed</td>
<td>Clone</td>
</tr>
<tr>
<td>5</td>
<td>18.88 (0.96)</td>
<td>19.98 (2.07)</td>
</tr>
<tr>
<td>25</td>
<td>18.30 (0.76)</td>
<td>19.35 (1.24)</td>
</tr>
<tr>
<td>35</td>
<td>18.25 (0.62)</td>
<td>20.16 (1.36)</td>
</tr>
<tr>
<td>55</td>
<td>18.21 (0.56)</td>
<td>20.11 (1.34)</td>
</tr>
<tr>
<td>65</td>
<td>18.12 (0.98)</td>
<td>19.65 (1.33)</td>
</tr>
<tr>
<td>90</td>
<td>17.57 (1.47)</td>
<td>20.18 (1.34)</td>
</tr>
</tbody>
</table>

Fig. 1. Variation of fibre length with stem height of the eucalypt hybrid Eucalyptus grandis × E. urophylla. Mean of 5 trees and half standard deviation as bar.

Fibre length

The tree average fibre length ranged from 0.824–1.035 mm and 1.009–1.108 mm respectively in the seed and clone trees. The between-tree variability was very small corresponding to a coefficient of variation of the mean of 9% and 4%, respectively, in the seed material and in the clone trees.
The fibre length values are in the same range of those reported for 7-yr-old *E. grandis × E. urophylla* hybrid trees, *i.e.* 0.81 mm (Grzeskowiak et al. 2000) and 1.08 mm (Carvalho & Nahuz 2001). The present values are also within the range reported for one of the parent species, *i.e.* 0.812 mm, 0.995 mm, 1.086 mm and 1.147 mm for respectively 3, 5, 7 and 9 years old *E. grandis* (Bhat et al. 1990) and 1.17 mm for 35 years old trees (Malan & Hoon 1992).

The *E. grandis × E. urophylla* hybrid shows fibre lengths similar to other eucalypt species used for pulping, *i.e.* 0.85 mm and 0.94 mm in 4.5-yr-old *E. tereticornis* (Rao et al. 2002), 0.82 mm to 0.93 mm in 7-yr-old *E. grandis × E. camaldulensis* (Grzeskowiak et al. 2000), as well as 0.89 mm to 0.93 mm in 9-yr-old, and 0.87 mm to 1.04 mm in 15-yr-old *E. globulus*, the important reference species for pulp production (Jorge et al. 2000; Miranda et al. 2001a, 2003; Miranda & Pereira 2002).

On average there was small axial variation of fibre length (Fig. 1) with a slight decrease towards the top, while in the clone trees an increase to the 25% level was noted followed by a decrease at 35% of tree height. The position along the stem was not a significant source of variation for fibre length.

Wilkes (1988) has described the axial pattern of fibre length variation in eucalypts as an initial increase and then a decrease at higher levels. This pattern was found in various mature eucalypts, *e.g.* in *E. globulus* (Jorge et al. 2000), *E. regnans* (Bisset & Dadswell 1949), *E. grandis* (Bhat et al. 1990), but Rao et al. (2002) found no trend of axial variation in 4.5-yr-old clones of *E. tereticornis*.

The radial variation of fibre length showed an increasing trend from pith to the periphery although of small magnitude (Fig. 2). This variation occurred in all height levels as exemplified in Figure 3 for one clone. For instance, fibre length varied from pith to the periphery (10% and 90% of the radius) in the clone trees from 0.93 mm to

![Fig. 2. Radial variation of fibre length of the eucalypt hybrid *Eucalyptus grandis × E. urophylla* at 5% of height level. Mean of 5 trees and half standard deviation as bar.](image-url)
1.11 mm at 5% height level and from 0.96 mm to 1.19 mm at the 65% height level. A paired t-test conducted at every radial position for seed and clone trees indicated highly significant differences with reference to radial position (Table 3).

Table 3. Radial variation of anatomical properties in clone and seed of the eucalypt hybrid urograndis (*Eucalyptus grandis* × *E. urophylla*). Mean of 5 trees and standard deviation in brackets.

<table>
<thead>
<tr>
<th>Radial distance</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>30%</td>
</tr>
<tr>
<td><strong>Fibre length (mm)</strong></td>
<td></td>
</tr>
<tr>
<td>Seed</td>
<td>0.834</td>
</tr>
<tr>
<td></td>
<td>(0.117)</td>
</tr>
<tr>
<td>Clone</td>
<td>0.929</td>
</tr>
<tr>
<td></td>
<td>(0.044)</td>
</tr>
<tr>
<td><strong>Fibre diameter (µm)</strong></td>
<td></td>
</tr>
<tr>
<td>Seed</td>
<td>17.44 abc</td>
</tr>
<tr>
<td></td>
<td>(1.30)</td>
</tr>
<tr>
<td>Clone</td>
<td>18.11 d</td>
</tr>
<tr>
<td></td>
<td>(1.47)</td>
</tr>
<tr>
<td><strong>Fibre wall thickness (µm)</strong></td>
<td></td>
</tr>
<tr>
<td>Seed</td>
<td>3.26 abc</td>
</tr>
<tr>
<td></td>
<td>(0.31)</td>
</tr>
<tr>
<td>Clone</td>
<td>4.02 cd</td>
</tr>
<tr>
<td></td>
<td>(0.38)</td>
</tr>
</tbody>
</table>

*** = significant at 0.001% level.

Means in the same row followed by a same letter are not significantly different at the 0.05 probability level.

Fig. 3. Radial variation of fibre length, at different height levels, of a clone tree of the eucalypt hybrid *Eucalyptus grandis* × *E. urophylla*. 
The pattern of increase in fibre length with cambium age has been shown for several species, e.g. *E. grandis* (Malan & Hoon 1992) and *E. globulus* of different tree ages (Jorge et al. 2000; Miranda et al. 2001a, 2003; Miranda & Pereira 2002). However, their pronounced initial increase in the inner part of the stem, corresponding to the first 2–4 years of cambium age, was not observed in these urograndis hybrid trees. From near the pith to the periphery, fibre length increased only by about 17%.

Overall fibre length remained rather constant within the stem regardless of tree and cambium age up to the maximum age studied (approximately 7 years), and the values obtained are similar to other eucalypts at harvest age for the pulp industry, i.e. *E. globulus* in Europe.

**Fibre width and cell wall thickness**

The fibre width was on average 18 μm and 20 μm in seed and clone trees, respectively, and cell wall thickness ranged from 3.4–3.9 μm and from 3.9–4.8 μm, respectively.

Similar values were reported for *E. grandis* × *E. urophylla* (17.1 μm and 4.2 μm) by Carvalho and Nahuz (2001) but Grzeskowiak et al. (2000) indicated, for two 7-yr-old clones fibre widths of 12–18 μm and much lower cell wall thickness values (2.4 and 2.6 μm). The values found in this study are similar to those reported for 7- and 18-yr-old *E. globulus* (Miranda et al. 2001a, 2003). The axial variation of fibre width and wall thickness was of very small magnitude, and differences between height levels were not statistically significant (Table 2).

The pattern of radial variation of fibre width corresponded to a small increase from pith to the periphery, and was similar in seed and clone trees at each tested height level (Fig. 4). For cell wall thickness there was also a general trend of increase from pith...
to the periphery at all height levels, with thicker fibres in the periphery than near the pith, which was more noticeable in the seed trees (Fig. 5). As it was observed for fibre length, the paired t-test for diameter and fibre wall thickness indicated significant differences with reference to radial position (Table 3).

The increase of cell diameter and wall thickness with age was also found by Grzeskowiak et al. (2000) in two clones of *E. grandis* × *E. urophylla* and in *E. grandis* seedlings, and in one clone of *E. grandis* × *E. camaldulensis*.

**Wood basic density**

The wood basic density ranged between 397–464 kg/m^3^ and 486–495 kg/m^3^, respectively, in seedling and clone trees (Table 1). As to be expected, the between-tree variation in the clone was very low, with a coefficient of variation of the mean below 1% (8% in the seedling material). These densities are close to the 460–491 kg/m^3^ reported for this hybrid in 5.6-yr-old trees (Bouvet & Baillères 1995; Gominho et al. 2001) and 8-yr-old trees (Padovan et al. 2001), and slightly below the values of 505 kg/m^3^ and 543 kg/m^3^ reported by Carvalho and Nahuz (2001) and Bassa (2002), respectively, for 7-yr-old trees.

The average values of wood basic density in the tested hybrid trees (Table 1) were similar to those reported for the parent species *E. grandis*, e.g. 495, 420, 485, 497 kg/m^3^ in 3, 5, 7, and 9-yr-old trees (Bhat et al. 1990), 426–532 kg/m^3^ in 8-yr-old trees (Marcos et al. 1998), 490 kg/m^3^ in 7-yr-old trees (Carvalho & Nahuz, 2001) and slightly lower than the 510 kg/m^3^ for 6-yr-old trees of *E. urophylla* (Vale et al. 2002). The wood density was similar to that of the important pulpwood species *E. globulus* at a similar age of 7 years (442–450 kg/m^3^, Miranda et al. 2001b), but under the density reported for 9-yr-old trees, ranging from 492 to 600 kg/m^3^ (Miranda et al. 2001c).
The variation of wood basic density along the stem was small, with a general pattern of a decrease from the base to the 25% height level followed by a small increase to the top (Fig. 6). For the clone, the between-tree differences were very small due to their genotypic uniformity, while the seedling trees showed a higher between-tree variability. The within-tree differences of wood density due to axial position were statistically significant (p < 0.05) in the clone trees but not in the seed trees.

The same pattern of axial variation was described for this hybrid with the same age (6–8 years) by Bouvet and Baillères (1995), Gominho et al. (2001) and Padovan et al. (2001), and similar trends were observed for *E. grandis* by Bhat et al. (1990), Wilkins

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**Fig. 6.** Variation of basic density with stem height of the eucalypt hybrid *Eucalyptus grandis* × *E. urophylla*. Mean of 5 trees.
(1991) and Marcos et al. (1998). The increase of wood density with tree height was observed as a general pattern of axial variation in eucalypts (Wilkes 1988; Zobel & Van Buijtenen 1989) but the initial decline of wood density between the 5% and 15% height levels before the increase upwards was also reported for some species, i.e. *E. globulus* and *E. nitens* (Raymond & Mineri 2001) and *E. globulus* (Quilhó & Pereira 2001).

The radial variation of fibre dimensions, namely of fibre width and wall thickness (Fig. 4 & 5) could not explain the differences in wood density. Although a Pearson correlation analysis between each of the fibre dimensions (length, width and wall thickness) and wood density for all stem height levels (a total of 60 observations) showed highly significant (*p* < 0.001) and positive correlations, the proportion of total variation of wood density that these factors could explain was low, e.g. wall thickness explained only 25% of the wood density variation and fibre width 16%. It is likely that other factors affect wood density such as vessel characteristics as well as the accumulation of extractives in heartwood that was reported to have a large and early development in the urograndis hybrid (Gominho et al. 2001).

**CONCLUSION**

The fibre dimensions of the Brazilian seed and clone urograndis hybrids, at the harvest age for the pulp industry (6–7 years), were similar to those of other eucalypt pulpwood species used as pulping raw-material, e.g. *E. globulus*, while the wood basic density was lower. The comparison between seed and clone trees showed that the clone had higher wood density, and longer, wider and thicker fibres.

Overall the within-tree axial and radial variation of these wood properties was small, and the age factor up to the studied age of 6.5 years had only a small impact on the variation of density and fibre dimensions. The between-tree variation was also very small, especially in the clone. These characteristics allow to obtain a substantial uniformity of wood properties in the pulpwod raw material harvested from such *E. grandis* × *E. urophylla* plantations, that is enhanced in the case of clonal material.

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