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EFFECT OF TREE AGE ON WOOD PROPERTIES OF *EUCALYPTUS CAMALDULENSIS* IN THAILAND

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ABSTRACT

The main objective of this study was to study the effect of tree age on basic density, chemical composition, and the fiber morphology of wood. The materials used in this study were 4, 6 and 8 years old *Eucalyptus camaldulensis* plantation trees from the same clone. The plantations located at the eastern part of Thailand and were not far from each other. All experiments were performed in laboratory scale. Three debarked wood disks from each tree age were cut at 1.3 m above ground for analyzing wood density, chemical composition, fiber length and coarseness, cell distribution and fiber wall thickness. The wood density of *E. camaldulensis* increased with increasing tree age; density level was high, 550 to 650 kg/m^3. Pentosan content decreased slightly while pitch content increased with age. There was a lot of tylose deposited inside the vessels of the 4th growth ring of 8 year old trees. Older trees had longer and coarser fibres, but the effect seemed to be leveled off at the age of 6 years. In general, fibre coarseness was very low. Vessel and fiber volumes increased from pith to bark, especially at the 6- to 8-growth rings of 8 years old trees. Tree age did not affect fiber diameter but wall thickness slightly increased while lumen decreased with increasing tree age.

INTRODUCTION

In general, pulp produced in Thailand is of short fiber type that mainly comes from eucalyptus, partially from bamboo and scantly from bagasse and other non-woods (Anonymous, 2001). Thailand does not produce softwood pulp because of the raw material limitation. Although *Eucalyptus camaldulensis* is the main pulp raw material, the studies concerning pulp quality are limited. To produce better pulp quality and a higher capacity, a study of *E. camaldulensis* wood, pulp and paper properties was therefore important for the Thai industry.

Previously, the harvesting age of eucalyptus for pulp and paper in Thailand was 4 to 5 years although the harvesting age to produce maximum amount of wood would be between 9 to 14 years. Now it has often been reduced to 2 to 3 years because of the regional economical crisis (Anonymous, 1999; Niskanen, 1997). It is generally recognized that tree age affects the wood properties, pulp yield and quality as well as biomass production. Therefore, optimum tree age is a very important criteria for improved pulp and paper quality and a low manufacturing cost. Thus the main objectives of this study was to study the effect of tree age on basic density, chemical composition and the fiber morphology of wood.

MATERIALS AND METHODS

Material Preparation

The trees used in this study were of three different ages and taken from *E. camaldulensis* plantations belonging to Forest Industry Organization in the eastern part of Thailand. They were 4, 6 and 8 years old. In each tree age, three trees were sampled thus in this study nine trees were used. Debarked disks from each tree age, by

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one disk taken from each tree, were obtained having 6 cm-thickness, being cut at 1.3 m above the ground. Each disk was divided into 3 smaller parts by cutting in the radial direction like pie pieces to analyze wood density and fiber morphology. For chemical composition, the wood meals of all same tree age disks were mixed before analyzed.

Wood Density and Chemical Composition

Wood density was determined in accordance with the method of Browning (1967a) in green basis (oven dry weight/ green volume) and dry basis (oven dry weight/oven dry volume). The wood disk was chopped into small pieces and then milled into wood meal. After that, the wood meal was screened through a 40 and 60-mesh screen. The over 60 mesh and under 40 mesh wood meal size fraction was accepted. The dry matter content of wood meal was measured according to SCAN-C 3:78. The standards used were the methods of wood chemistry by Browning (1967b) for analyzing holocellulose, pentosan and ash content, and TAPPI T222-om 88 for analyzing lignin content.

Fiber Length and Coarseness

Small particles like matchsticks were prepared from the wood disks. These particles were macerated using acetic acid and hydrogen peroxide to obtain liberated delignified fibers. Minisheets were prepared according to the Seth and Chan method (Seth and Chan, 1997). The fiber length and fiber coarseness were measured by Kajaani FS-200 according to TAPPI T271 pm-91.

Cell Type Distribution

The cross section slides were prepared from the wood disks. A photograph of each annual ring (4-, 6- and 8-growth rings) was taken by a camera attached to a microscope at 10 X magnification. The vessel and parenchyma area of each cross sectional image was measured using a dot grid of 10 X 10 cm size, representing a 0.8 mm^2 wood area, and 10,000 dots. The fiber area was calculated from the difference between the total area and the area of vessel and parenchyma.

Fiber Dimension

For cell wall thickness, a photograph of each annual ring was taken at 100X magnification. The measurement was done in radial direction. The total width of two common cell walls of three adjoining fibers and the intervening lumen was measured. To obtain the thickness of single cell wall, the lumen measurement was subtracted from the overall measurement and the difference divided by 4 (Hiller, 1964).

RESULTS AND DISCUSSION

Wood density

The wood densities of 4- to 8-year-old *E. camaldulensis* in this study ranged from 530 to 640 kg/m^3 (green basis) and 610 to 760 kg/m^3 (dry basis) as shown in Figure 1.

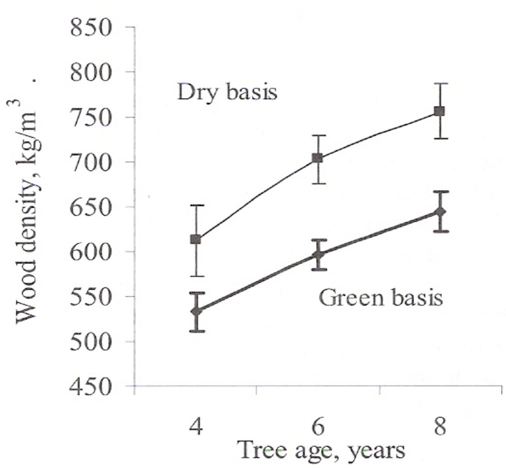

Figure 1. The relationship between wood density and tree age. A pair of bars is denoted at 95% confident level.

For within tree variation, the wood densities of the first to the forth growth rings of 4- to 8-year-old trees varied from

533 to 630 kg/m^3 (green basis) and from 612 to 740 kg/m^3 (dry basis) as shown in Figure 2. The density variation of 8-year-old wood from pith to bark was 630 to 617 kg/m^3 (green basis) and 740 to 674 kg/m^3 (dry basis) as shown in Figure 3.

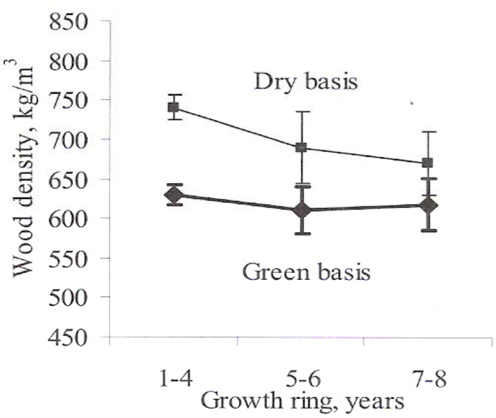

Figure 2. The development of wood density of the 1-4 growth ring part of trees of 4- to 8-years old. A pair of bars is denoted at 95% confident level.

The wood density increased with increasing tree age. At the same growth ring, the younger trees had lower density than the older trees. It possibly comes from the development of heartwood, which contains extractives deposited inside vessels called tyloses. These tyloses make the heartwood to be denser than the sapwood. Thus, the highest density of 8-year-old trees was possible due to the highest heartwood formation of 1- to 4-growth rings.

The basic density of *E. camaldulensis* wood specimen in this study was higher than in other studies. Densities of 6-years-old trees of nine eucalyptus species from South Africa were 532$\pm$35 kg/m^3 in colder sites and 477$\pm$35 kg/m^3 in warmer sites (Clarke *et al*., 1997; 1999). The 10 years old *E. globulus, E. nitens, E. viminalis* and *E. grandis* from different regions in Australia (O'Neill *et al*., 1996) and 6 to 12 years old *E. deglupta* from Philippines (Orme *et al*., 1996) also gave lower densities (300 – 400 kg/m^3) than the eucalyptus trees used in this study.

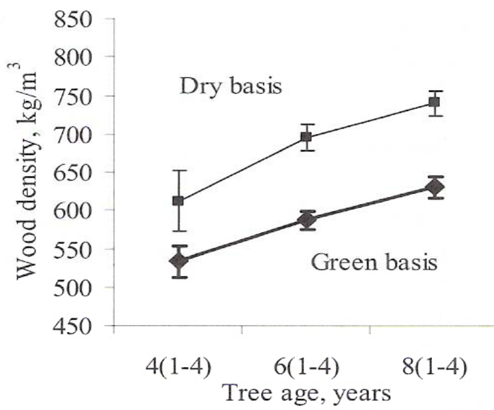

Figure 3. The within tree variation of Wood density from 1-4 growth ring to 7-8 growth ring at 1.3 m above ground of 8-year-old. A pair of bars is denoted at 95% confident level.

Chemical Composition

The *E. camaldulensis* samples composed of 71.9 to 72.5% of holocellulose, 26.9 to 27.1% of lignin, 13.8 to 15.3% of pentosan, 7.5 to 8.8% of extractive and 0.7 to 1.1% of inorganics (ash content). In this study, the differences in wood chemical composition were small and the tree age only slightly affected the chemical composition as shown in Figure 4. The holocellulose, lignin and ash contents were approximately unchanged with increasing tree age. However, the extractive content increased and pentosan content decreased with increasing tree age. Thus, the heartwood of old eucalyptus should be avoided as raw material for pulping.

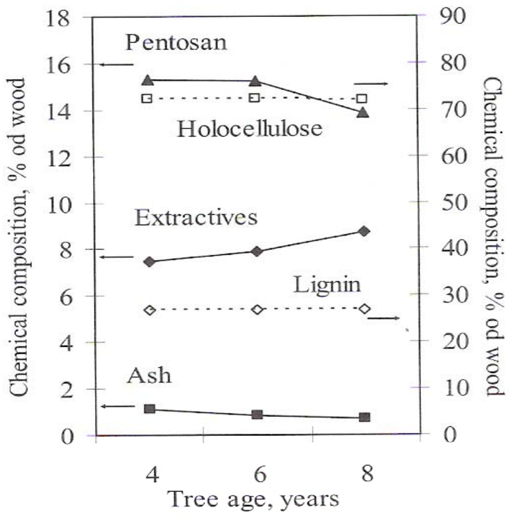

Figure 4. Effect of tree age on wood chemical composition at 1.3 m above ground.

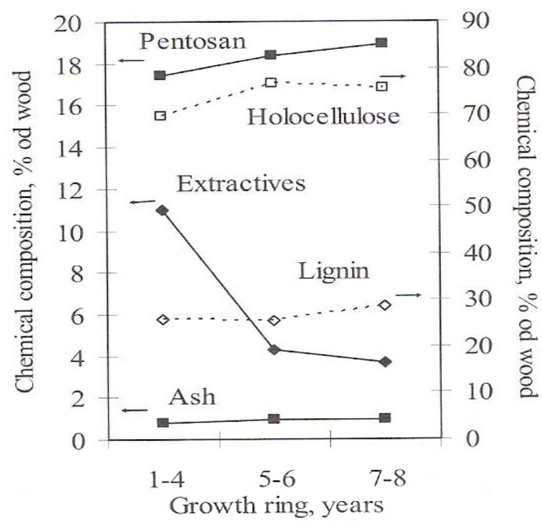

Figure 5. The within tree variation of chemical composition from pith to bark at 1.3 m above ground of 8-year-old trees.

Klason lignin content in this study was slightly lower than 5-year-old *E. camaldulensis* from Thailand (29%) in another study (Pattanopast, 1995) but it was clearly higher than 6- to 32-year-old *E. globulus* (18.2-23.2%) (Willis *et al*., 1995). Holocellulose, pentosan and extractive contents were not much different from 5-year-old *E. camaldulensis* from Thailand (72%, 12% and 8%, respectively) (Pattanopast, 1995). The *E. camaldulensis* in this study gave ash content as low as that from Spain (Conde *et al*., 1995). The chemical composition of *E. camaldulensis* in this study was similar to the previous studies of *E. camaldulensis* in Thailand.

For within-tree variation, ash, holocellulose, lignin and pentosan contents increased from pith to bark while extractive content decreased. At the same growth ring younger trees gave the higher ash, holocellulose and lignin while extractive and pentosan content were lower than older trees as shown in Figure 5. The higher extractive content of 1- to 4-growth ring of 8-year-old wood possibly originated from tylose deposited in vessel of heartwood.

Fiber Length and Coarseness

Chips, pulps, and wood disks produced from 4- to 8-year-old *E. camaldulensis* gave fibers with the average length (length-weighted) from 0.7 to 0.8 mm (Figure 6) and with the coarseness from 43 to 50 μg/m (Figure 7).

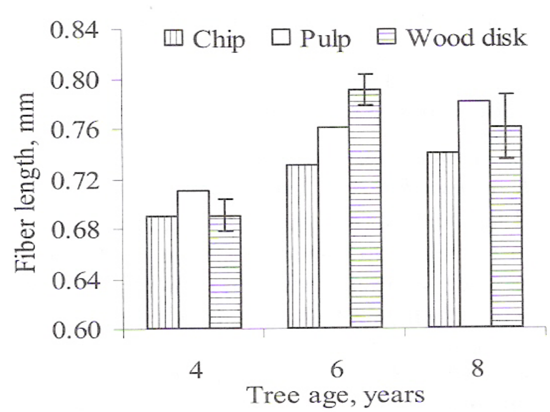

Figure 6. Effect of tree age on length-weighted average fiber length.

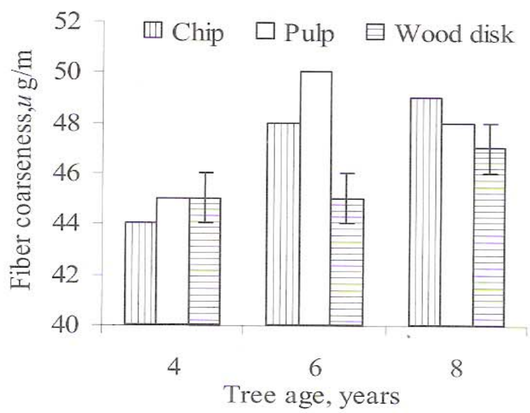

Figure 7. Effect of tree age on fiber coarseness.

The fiber length was not much different from fiber length of other studies, for example, Thai and Vietnamese *E. camaldulensis* (0.69 mm and 0.68 mm) (Widjaya, 2001; Lap, 1999) and Portuguese *E. globulus* (0.73 mm) (Carvalho *et al.*, 1997). However, it was longer than commercial *E. camaldulensis* fibers from Northeastern, Thailand (0.63 mm) (Nontathai, 1999) and 6-year-old *E. grandis* from South Africa (0.58 mm) (Clarke, 2000). This length was shorter than that of 8- and 11-year-old *E. globulus* from New Zealand (0.85 mm) (Kibblewhite *et al.*, 2001) and 10-year-old *E. globulus* and *E. grandis* from Portugal (0.87 and 0.93 mm) (Cotterill and Macrae, 1997).

Fiber coarseness was lower than that of *E. camaldulensis* from Vietnam (73 µg /m) (Lap, 1999), Thailand (54 µg /m from mill in the Eastern part and 82 µg /m from mill in the Northeastern part) (Widjaya, 2001; Nontathai, 1999). It was also lower than that of other eucalyptus species, for example, 10-year-old *E. globulus* and *E. grandis* from Portugal (72 and 70 µg /m) (Cotterill and Macrae, 1997).

The fiber length and coarseness of *E. camaldulensis* significantly increases with increasing tree age, according to O'Neill *et al.* (1995). At the same growth ring, the fiber length and coarseness of 4- to 8-year trees should not be different but in this study they were slightly different as shown in Figures 8 and 9, possibly due to the different plantation sites and/or because of normal variation of the results.

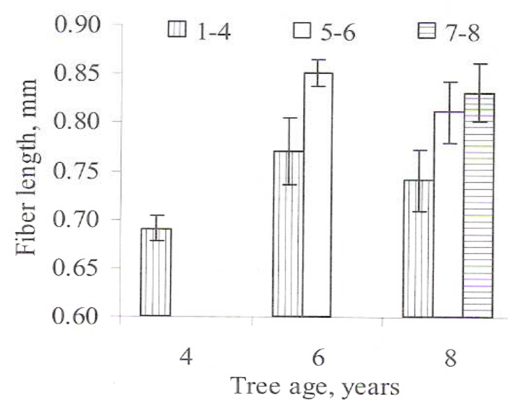

Figure 8. Within tree variation of length-weighted average fiber length at 1.3 m above ground of 4- to 8-year-old trees. A pair of bars is denoted at 95% confident level.

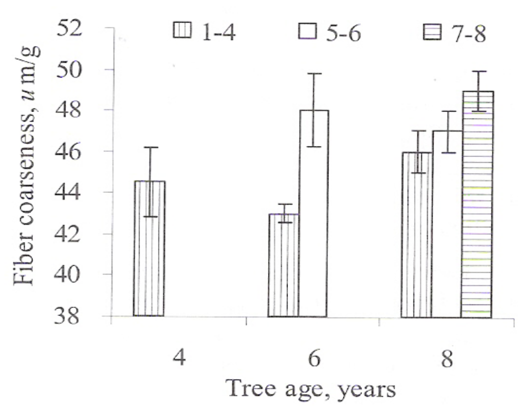

Figure 9. Within tree variation of fiber coarseness at 1.3 m above ground of 4- to 8-year-old trees. A pair of bars is denoted at 95% confident level.

Although the different aged trees came from different plantations, the within-tree variation from pith to bark of 6- and 8-year-old wood disks showed the same trend.

Cell Type Distribution

The percentage areas of vessel, parenchyma and fiber cells were 14-21%, 25-27% and 51-61%, respectively. For the 8-year-old tree, vessel area percentage was constant from 4- to 6-growth rings and then increases from 6- to 8-growth rings while the parenchyma area percentage was entirely constant as shown in Figure 10. For the 6-year-old tree, vessel and parenchyma volume increased from 4- to 6-growth rings. Consequently, the fiber area percentage decreased from pith to bark. Similarly, the vessel area of *E. globulus* from Australia was found to increase from pith to bark (Clark, 1990).

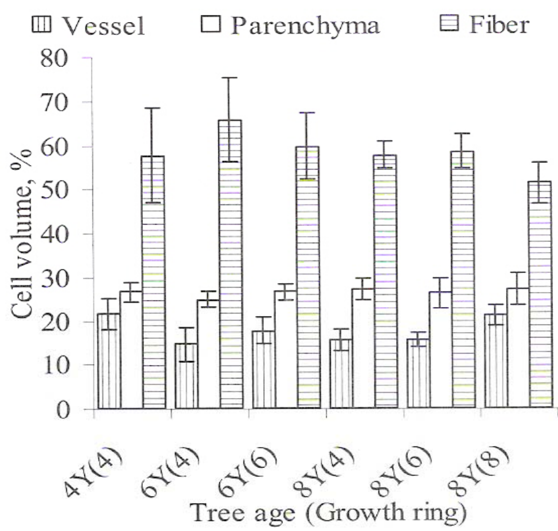

Figure 10. **Vessel, fiber and parenchyma cell distribution at 4-, 6- and 8-growth rings of 4- to 8-year-old trees at 1.3 m above ground. A pair of bars is denoted at 95% confident level.**

For within tree variation, the vessel volume of the inner part of the tree was less than that of the outer part while the fiber volume gave the inverse trend. The volume of vessel is the main effect on wood density of hardwood. The lower volume of 4-growth ring vessels had the tendency to raise the wood basic density.

In addition, from the photograph of cross section slide of wood, the 4-growth ring vessels of 8-year-old wood were filled with tyloses as shown in Figure 11. It is possible that the tylose in vessel cavity affected the wood density of inner part of the tree. In 6-year-old tree, there was no tylose depositing in the vessel lumen of 4-growth ring. The tylose deposit may be a cause of the cooking difficulty.

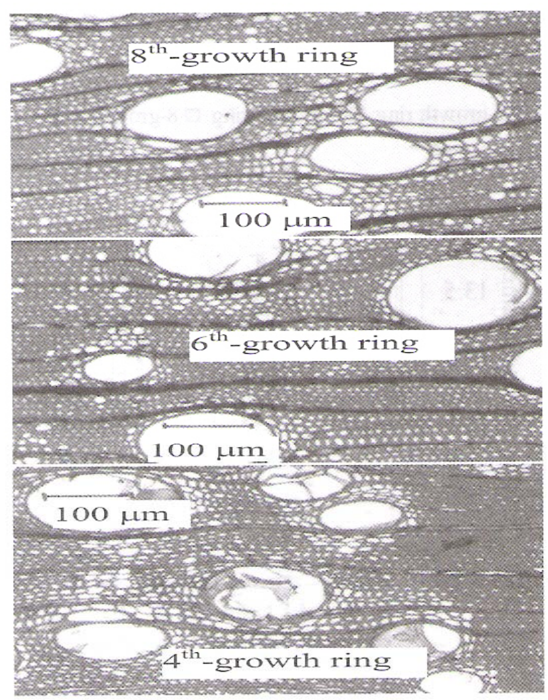

Figure 11. **The wood cross section of 4- to 8-growth rings of 8-year-old tree. The tylose had deposited in the 4-growth ring**

Fiber Dimension

The diameter, lumen and wall thickness of 4- to 8-year *E. camaldulensis* fibers were 13.2 to 13.9, 5.4 to 7.5 and 3.2 to 3.9 micrometer (µm), respectively. *E. camaldulensis* gives slightly smaller fiber diameter than the other eucalyptus and hardwood species; for example, *E. globulus* (12.8 to 14.9 µm), *E. grandis* (13.4 to 16.0 µm), birch (16.1 to 18.6 µm), aspen (17.6 µm) and mixed hardwoods (15.8 to 16.3 µm) but it gives the slightly thicker fiber wall (Kibblewhite *et al*., 1991).

The fiber diameter of 4- to 8-year-old trees was not much different from each other and for within tree variation, both of 8- and 6-year-old trees gave the slightly decreasing fiber size from pith to bark as shown in Figure 12. Thus, tree age did not markedly affect fiber diameter.

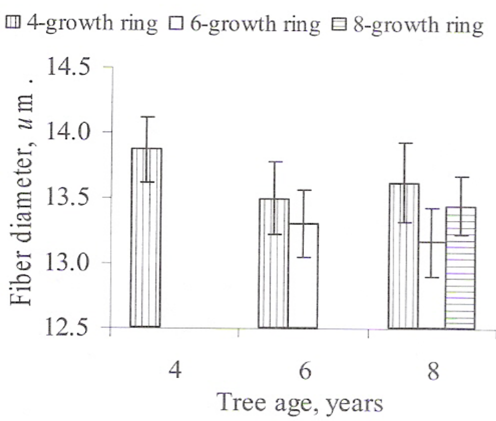

Figure 12. **Fiber diameter of 4- to 8-year-old trees at 4-, 6- and 8-growth rings. A pair of bars is denoted at 95% confident level.**

On the other hand, wall thickness seemed to increase while lumen decreased with increasing tree age as shown in Figures 13 and 14. However, for within tree variation, from the 6- to 8-growth rings of 8-year-old tree, the wall thickness decreased while lumen size increased, which possibly came from the effect of climate corresponding to the increase of vessel volume.

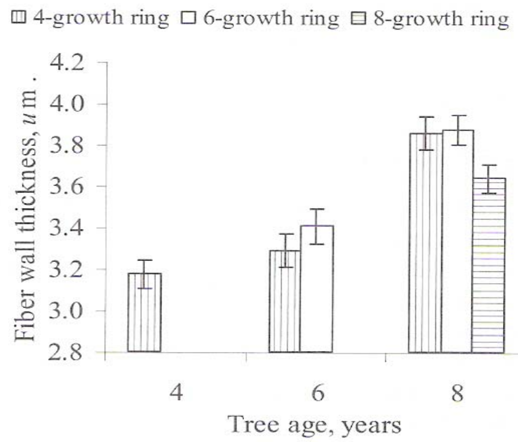

Figure 13. **Fiber wall thickness of 4- to 8-year-old trees at 4-,6- and 8-growth rings. A pair of bars is denoted at 95% confident level.**

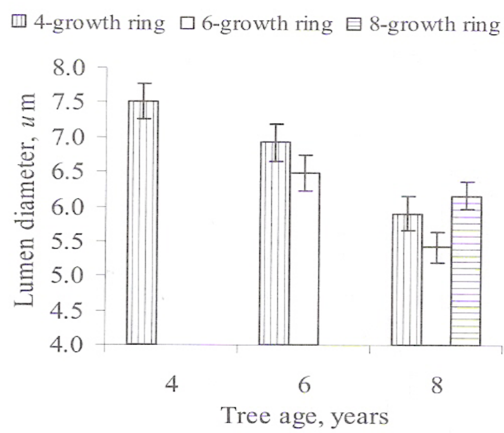

Figure 14. **Lumen diameter of 4- to 8-year-old trees at 4-, 6- and 8-growth rings. A pair of bars is denoted at 95% confident level.**

The 4-growth ring of a 4-year-old tree gave the thinnest wall thickness and largest lumen and diameter while the 4- and 6-growth rings of 8-year tree gave the thickest wall and smallest lumen. In addition, the different lumen size of 4- to 8-year-old trees possibly affected the wood basic density. The smaller lumen and the thicker fiber wall, the higher wood density.

CONCLUSIONS

The 4, 6 and 8 years old of *Eucalyptus camaldulensis* plantation trees from the same clone were studied. Three debarked wood disks from each tree age were cut at 1.3 m above the ground for analyzing wood density, chemical composition, fiber length and coarseness, cell distribution and fiber dimension. The main objectives were to study the effect of tree age on the wood properties.

1) The older trees gave higher basic densities although it did not sharply vary from pith to bark. The density of the 1- to 4-growth rings of 8-year-old trees was very high. It possibly comes from the tylose deposited in the vessel. The densities of the 8-year-old trees were higher than the recommended level of 600 kg/m^3 for pulping.

2) Pentosan content slightly decreased while extractive content increased with increasing tree age. Tree age did not affect holocellulose, lignin and ash contents. The extractive content of 1- to 4-growth rings of 8-year-old wood was very high because there were a lot of tyloses deposited inside the vessels.

3) The 4-year-old wood gave the finer and shorter fibers than the 6- and 8- year old ones.

4) For within tree variation, the vessel volume increased but fiber volume decreased from pith to bark, especially at the 6- to 8-growth rings of 8 years old trees.

5) Tree age did not affect fiber diameter but wall thickness slightly increased while lumen decreased with increasing tree age. However, the changes were small.

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