Journal of Agricultural Science and Technology A 4 (2014) 129-134
Earlier title: Journal of Agricultural Science and Technology, ISSN 1939-1250

Ethylene Stimulation of Rubberwood (*Hevea brasiliensis*) Increases the Water Permeability of Lumber

Banyat Cherdchim and Rossarin Sudchada
Faculty of Sciences and Industrial Technology, Prince of Songkla University, Surat Thani Campus, Muang District, Surat Thani 84000, Thailand

Received: November 14, 2013 / Published: February 20, 2014.

Abstract: *Hevea brasiliensis* Muell. Arg. is an important industrial crop for natural rubber production. Latex biosynthesis occurs in the cytoplasm of highly specialized latex cells and latex bleeds out when the bark is tapped. Ethylene stimulation acts by increasing latex flow to the cells of inner bark from the latex cells, increasing yield and may affect the physical properties of rubberwood. The aim of this work was to assess the permeability properties of ethylene treated rubberwood (TRW) relative to untreated rubberwood (URW), because in wood industrial technology, permeability relates to bondability and wood preservative treatments. The *Hevea* samples were of PRIM 600 strain, from 20-25 years old rubber trees. The TRW rubber trees had been stimulated by ethylene gas for six years. The rubberwood specimens were collected at a single plot of plantation to minimize variations in soil fertility, environmental exposures and silvicultural treatments at Tumbon Chaibury, Amphor Chaibury, Suratthani Province, Thailand. The moisture contents (MC) of fresh rubberwood were significantly different ($P < 0.05$) at 75% for TRW and 64% for URW. The permeability experiment followed Darcy's law, and the hydrostatic pressure was controlled. The average 0.005 Darcy water permeability of TRW was significantly higher than the 0.001 Darcy for URW. Water absorptions during 4 h water immersion of rubberwood blocks differed significantly, and TRW had higher absorption than URW also across 6 d of immersion. Scanning electron microscope (SEM) imaging showed anatomical effects that contribute to the fivefold permeability increase.

Key words: Ethylene, permeability, rubberwood, water absorbance, water diffusion.

1. Introduction

Currently rubber tree farmers stimulate rubber trees with ethylene to improve the latex yield of trees 15 years or older, and the trees are felled around 25-30 years age. While ethylene stimulation benefits latex yield, it might also impact the physical properties of rubberwood lumber. When the stimulation used holes bored into wood, it generated injures and changed the color of lumber decreasing the value of lumber. These problems have decreased with a new generation of ethylene treatments such as RRIMFLOW technique, where stimulating ethylene passes through the wood bark without drilled holes. However, the physical, mechanical or other key properties of wood lumber may be affected by ethylene treatment, and this is an area with current gaps in knowledge.

At the Suratthani Rubber Research Center (Thailand) [1], they have studied the moisture content and shrinkage-swelling of ethylene treated rubberwood, but no significant treatment effects were observed. Effects on chemical composition have been studied, and there are reports that ethylene treated rubberwood (TRW) had higher lignin and extractive contents than untreated rubberwood (URW) [2]. Moreover, the TRW had higher resistance to white rot fungi *Schizophyllum commune* and *Garnoderma* spp. than URW, in experiments with 12 weeks of incubation at 22 °C, RH 65%. The penetration rate of boron compounds (disodium octaborate tetrahydrate (DOT)) into TRW was higher than into URW [3]. DOT is a conventional wood preservative chemical

Coresponding author: Banyat Cherdchim, Ph.D., research field: wood technology. E-mail: banyat.c@psu.ac.th.

that induces slight color changes in wood. It is low cost and locally available. The reports have shown increased penetration rate of urea formaldehyde (UF) and bondability for TRW relative to URW [4]. These results suggest that the permeability of TRW is higher than that of URW, but the water permeability has not been determined. Knowing the treatment effects on this fundamental physical property will benefit industrial use of rubberwood enabling informed decisions. While there have been many studies on the latex yield from rubber tree plantations [5-8], the treatment effects on lumber properties have been less well studied. In the current study, we focused on water permeability.

Hevea brasiliensis Muell. Arg. wood is especially attractive because it is a fast growing plantation tree with a high potential for sustainable lumber production, and also otherwise of interest to the wood products industries. The current practice of ethylene stimulating *H. brasiliensis* needs to be assessed for its impacts on wood anatomy, which in turn might affect chemical preservative treatments or adhesive bonding. In this work, Darcy's law [9] was applied to water permeability in wood. The authors also determined the water absorbance and water diffusion rates in wood.

The current research was motivated by the needs of both rubber farmers and the industries that use rubber wood. If the effects of farming practices on wood quality are well understood and can be adapted to, it could increase the value of the wood raw material, what should benefit also the seller. The scope of this research is of necessity quite limited in relation to this general motivation, but relates strongly to the preservation treatment that is of primary importance for wood products.

2. Materials and Methods

2.1 Moisture Content in Wood

The fresh *H. brasiliensis* wood specimens were collected at Tumbon Chaibury, Amphor Chaibury, Suratthani Province, Thailand. The six rubberwood blocks of 30 mm (longitudinal) × 30 mm (tangential) × 30 mm (radial) were oven dried at 103 ± 2 °C for 24 h. The moisture content (MC) of wood was calculated as:

$$MC = \frac{M_G - M_{OD}}{M_{OD}} \times 100\%$$

where, M_G is the green mass of the wood, M_{OD} is its oven-dry mass.

2.2 Permeability of Wood to Water

Six *H. brasiliensis* wood blocks of 150 mm (longitudinal) × 10 mm (tangential) × 5 mm (radial) were oven dried at 103 ± 2 °C for 24 h, then mounted onto the ends of about 2 m long rubber tubes (9 mm in diameter) with about 5 mm length in the longitudinal direction within the tubes. In order to prevent solvent to leak out from the other surfaces of the wood blocks, the rest of the wood blocks were sealed with parafilm (Laboratory Film, Chicago, USA) leaving only the surface of the cross-section at the open ends of wood blocks free. The rubber tubes were fitted onto outlets affixed close to the bottom of a 500 mL plastic container. The plastic container was positioned on a shelf at about 2 m height, and the wood sticks in the rubber tubes were hanging in the opening of a 600 mL bottle standing on the floor. Water was filled into the 500 mL plastic box and with a natural hydrostatic pressure of about 20 kPa (calculated from $P = \rho h g$; P = hydrostatic pressure (Pa), ρ = fluid density (kg/m^3), h = the height (m), g = gravitational acceleration (m/s^2)). The water amount collected in the bottle over 30 min was weighed to determine the permeability of the wood sample. The distilled water was at ambient temperature (30 °C), and in the calculations it was assumed to have 1 cP viscosity. The permeabilities determined are for the axial direction, parallel to the wood fibers.

2.3 Water Absorbance and Water Diffusion in Wood

The wood blocks were cut into four smaller blocks of size 30 mm (longitudinal) × 10 mm (tangential) × 5 mm (radial) each, discarding 1.5 cm from both ends.

These blocks were dried and used in water absorbance determinations. Dried UTR wood blocks (size 30 mm (longitudinal) × 10 mm (tangential) × 5 mm (radial)) served as control. Six wood blocks for each type of wood were immersed into distilled water at ambient temperature, and the mass weighed every 15 min up to 4 h of total immersion time.

In another set of water absorbance experiments, six oven dried blocks of each type of *H. brasiliensis* (30 mm (longitudinal) × 10 mm (tangential) × 5 mm (radial), dried at 103 ± 2 °C for 24 h) were immersed into distilled water at ambient temperature, and mass weighted every day up to 6 d of immersion.

2.4 Statistical Analysis

Group values for all parameters in the tests were compared by Kruskal-Wallis tests (SPSS 8.0 for Windows, USA). In particular the treated vs. control contrast was analyzed.

3. Results and Discussion

The fresh wood moisture contents were determined as 64% for URW and 75% for TRW (Fig. 1), respectively.

During oven drying at 103 ± 2 °C for 24 h, TRW shrunk more than URW, especially in the radial direction (Fig. 2). It suggests that ethylene treatment may impact severely wood shrinkage or moisture induced swelling, and limit applications where dimensional stability is critical.

H. brasiliensis wood blocks of 150 mm (longitudinal) × 10 mm (tangential) × 5 mm (radial) were used to determine the axial permeability and potential treatment effects on it (see "Materials and Methods" for details). The statistically significant treatment effects on permeability to water are illustrated in Fig. 3. TRW had almost five fold permeability relative to URW.

There are reports on permeability (Table 1) of different softwoods and hardwoods from the outer heartwood part [9, 10]. Our wood samples were selected from a part between sapwood and heartwood. The values shown in Table 1 corroborate our permeability values as reasonable for wood samples.

3.1 Effects of Water Immersion on H. brasiliensis Wood

H. brasiliensis wood was tested at room temperature (30 °C). The total mass of each sample was weighed every 15 min to monitor the rate of water absorption. Absorption continued over the observed about 4 h (Fig. 4). After immersion for 1 h, the moisture content (MC) of URW was 21% and 24% for TRW. Throughout the rest of the observation span TRW had about 5% higher MC than URW (Fig. 4). The MC of wood is composed of both bound water and free capillary or pore water [11], but these cannot be distinguished from the time profiles of absorption. The rapid initial water uptake takes place because the sample surfaces were initially dry. Further water absorption into the inner sample must diffuse through that expanding wetted surface layer, and this increasing diffusion distance slows down the absorption rate.

A similar immersion test with distilled water at room temperature (30 °C) was extended to total duration

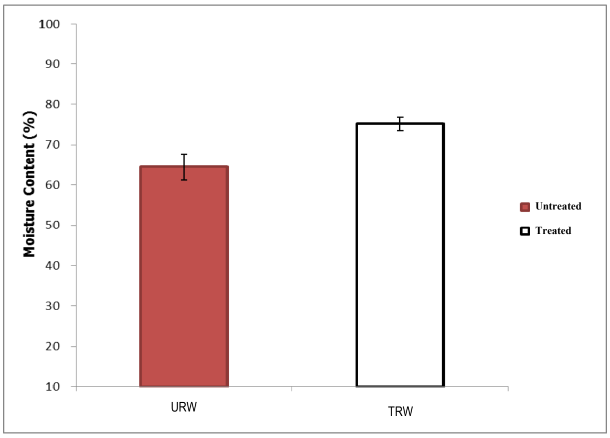

Fig. 1 Moisture contents of *H. brasiliensis* wood blocks of 30 mm (longitudinal) × 30 mm (tangential) × 30 mm (radial) were determined by oven drying at 103 ± 2 °C for 24 h or until stable mass.
Ethylene treated rubberwood is labeled TRW and untreated rubberwood URW. The averages of six replicates were significantly (P < 0.05) different between the treatments based on Kruskal-Wallis analysis.

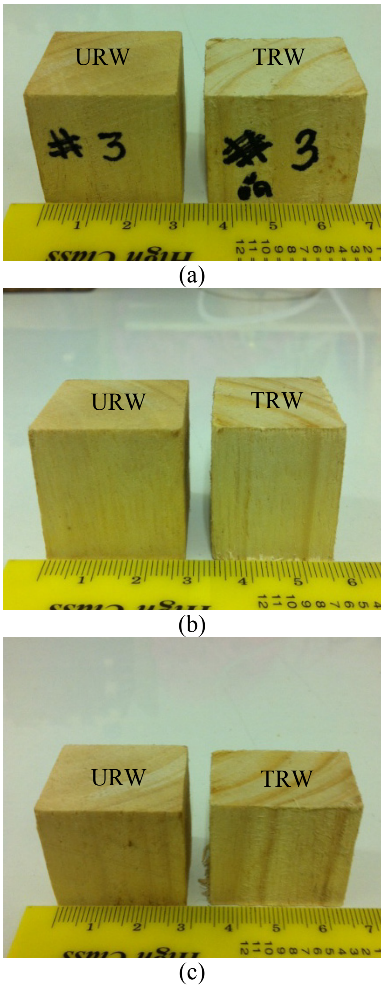

Fig. 2 Images illustrating the shrinkage of *H. brasiliensis* wood blocks initially 30 mm (longitudinal) × 30 mm (tangential) × 30 mm (radial) cubes, induced by drying at 103 ± 2 °C for 24 h or until stable mass.
Ethylene treated rubberwood is labeled TRW and untreated rubberwood URW. (a) longitudinal wood shrinkage; (b) radial wood shrinkage; (c) tangential wood shrinkage.

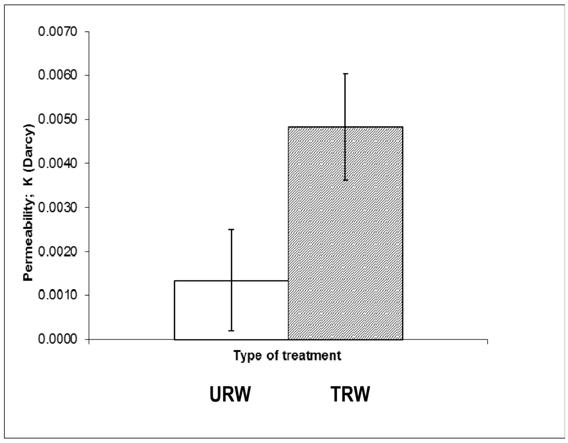

Fig. 3 Permeabilities, K (Darcy) of *H. brasiliensis* oven dried wood blocks when water was forced axially through them over a 30 min period.
Ethylene treated rubberwood is labeled TRW and untreated rubberwood URW, with six replicates in each treatment group the permeabilities differed significantly ($P < 0.05$) between treatments according to Kruskal-Wallis analysis.

Table 1 Water permeability of outer heartwood [9, 10].

Permeability by species	Permeability, Darcy	
	Mean	Standard error
Douglas fir	0.006	0.001
Lodgepole pine	0.001	0.0007
Engelmann spruce	0.007	0.0006
Eucalyptus grandis	0.0042	0.0025

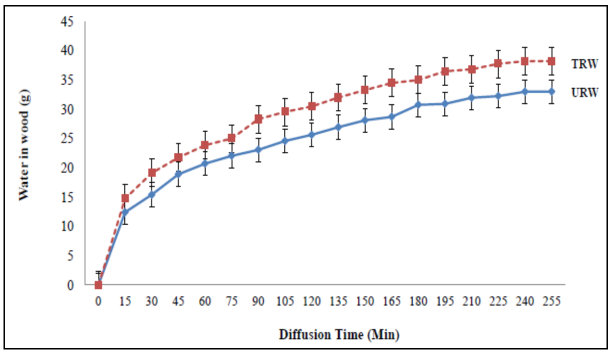

Fig. 4 Water absorption time profiles of immersed *H. brasiliensis* wood blocks of 30 mm (longitudinal) × 15 mm (tangential) × 10 mm (radial), initially oven dry.
Ethylene treated rubberwood is labeled TRW and untreated rubberwood URW with six replicates in each treatment group. The absorption profiles were significantly different.

of 6 d with daily observations as shown in Fig. 5. TRW samples consistently had higher MC than URW samples at equal immersion time as before. The MC increased consistently throughout the experiments, and the highest MC was about 90%. Factors or mechanisms that contribute to the slow long-term absorption may include the dissolution of gases into water from the pore space, enabling higher water saturation in blind pores and slow swelling of the samples that increases their pore volume.

From prior research [12] we know that radial trunk growth is related to access to water and carbon. Carbon is the basic chemical element for structural compounds and for storage of metabolic energy, and so are the atoms of water molecules. Stem radial variations reflect four main factors: (1) irreversible radial growth; reversible shrinkage and swelling affected by (2) hydration, (3) thermal expansion and

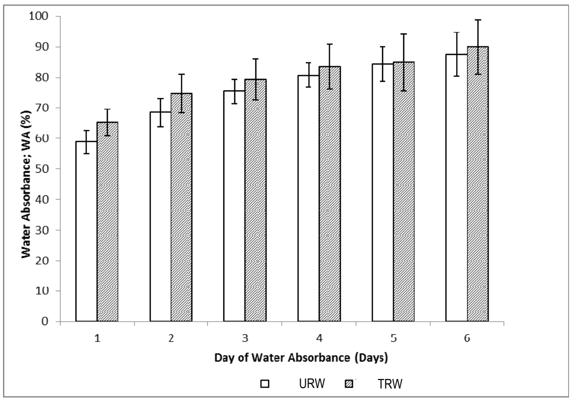

Fig. 5 MC profiles of treated and untreated wood samples which were initially oven dried during immersion in water over 6 d.

Table 2 Elemental analysis by % mass of *H. brasiliensis* wood samples from two treatment groups.

Wood	Element (SD) (%)				
	N	C	H	S	O
TRW	0.41 (9.49×10^{-3})	45.09* (0.28)	6.22 (3.47×10^{-2})	< 0.01	41.29 (0.18)
URW	0.40 (5.74×10^{-3})	44.86* (5.28×10^{-2})	6.22 (3.57×10^{-2})	< 0.01	41.22 (0.23)

Ethylene treated rubberwood is labeled TRW and untreated rubberwood URW;
*indicates the element content is significantly different between treatments.

(4) contraction and expansion of conducting elements, also responding to internal mechanical stresses [8, 12]. No significant treatment effect on radial trunk growth has been detected [7, 8]. Also high frequency tapping may affect the MC and growth rate of a rubber tree. It has been reported that URW had girth increment superior to TRW [13]. The TRW cases may have suffered from overexploitation and overstimulation. The increased latex yield of TRW necessitates higher consumption of water and carbon sources than by URW, relating to our measurement results (Fig. 1, Table 2). An elemental analysis of C, H, N and O was carried out with a CHNS-O analyzer, CE Instrument Flash EA 112 Series, Thermo Quest, Italy. The analyzer used dynamic flash combustion with left furnace temperature of 900 °C, oven temperature 65 °C, carrier flow 130 mL/min, reference flow 100 mL/min and oxygen flow 250 mL/min. In case of oxygen analysis, the parameters were: right furnace 1,060 °C, carrier flow 130 mL/min and reference flow 100 mL/min. The TRW cases had higher fraction of carbon than the URW (Table 2).

The results presented in Figs. 3-5 indicate that ethylene stimulation enhances permeability and water absorption of rubberwood probably through an effect on porosity. Porosity is defined as the fractional volume of voids that could be filled by a fluid in the solid structure. Ethylene treatment of *Populus alba* L. hardwood causes the cambium to produce more parenchyma, shorter fibers and shorter vessel elements than in control [14]. Application of ethylene to stem of *P. alba* causes abnormal growth and stem anatomy with an increase in wood and bark. The treatment has pleiotropic effects on dimensions of xylem cells and tissue pattern. Moreover, the tangential width of radial wood parenchyma cells increases; the wood cells are big and plasma rich with simple pits of different sizes and shapes. Ethylene treated wood may have normal xylem aside from the increased size of xylem rays that have more and larger cells than rays of the control [14, 15].

The fresh wood densities were determined as 0.94 g/cm^3 for URW and 0.91 g/cm^3 for TRW. The wood pit density and vessel diameter increments are likely causes of increased permeability in ethylene stimulated rubberwood (Fig. 6). The influence of ethylene stimulation on rubberwood structure was imaged with scanning electron microscope (SEM). Figs. 6a and 6b show that the treatment increased vessel diameters (single pore (SP)) to an average of 230-270 µm from 200-240 µm. In the double pores (DP), TRW had vessel diameters of 300-440 µm while the control had 240-380 µm (Figs. 6a and 6b). The simple pits in Fig. 6c had higher density in TRW than in URW (Fig. 6d) increasing permeability (Figs. 3-5). Thus, increment of vessel diameter and wood pit density of TRW are observed factors evidently contributing to water permeability and absorption increases.

4. Conclusions

Ethylene stimulation of rubberwood improved the axial water permeability of lumber relative to rubberwood

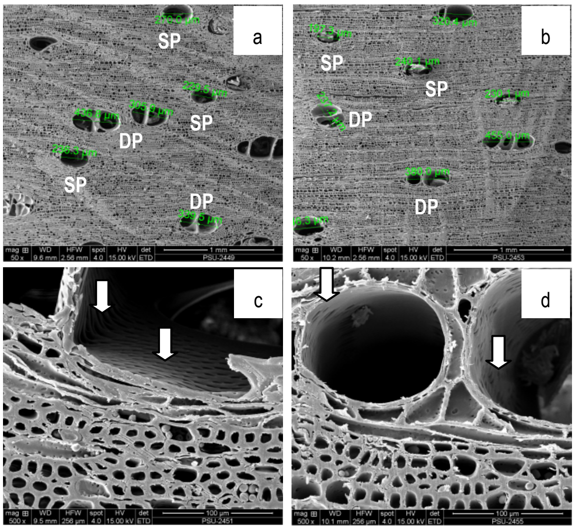

Fig. 6 SEM images of the structure of *H. brasiliensis* illustrate treatment effects contributing to increased permeability.
(a) cross section of TRW, (b) cross section of URW, the pit density is evident in (c) cross section of TRW and (d) cross section of URW; a-b scale bar = 1 mm, b-c scale bar = 100 μm; arrows point to the pits in vessel cell walls.

without ethylene treatment. The increase in axial permeability to water by ethylene treatment of *H. brasiliensis* was about five fold. Scanning electron microscope imaging suggested that ethylene treatment increased the areal number density of pits and the average vessel diameter. These physiological effects likely contributed to increases in water absorption rate and permeability to water of wood.

Acknowledgments

The authors thank Prince of Songkla University for financial support as well as its Scientific Equipment Center. The helpful comments and suggestions from Dr. Seppo Karrila are gratefully acknowledged.

References

[1] K. Sangsing, P. Parechana, W. Prommee, The comparison of wood product, wood quality and properties of ethylene stimulated wood, Journal of Rubber: Suratthani Rubber Research Center (Thailand) 1 (2009) 10-15. (in Thai)

[2] T. Damkleang, T. Poonchauy, B. Cherdchim, Study of effect of tapping by using ethylene gas on the chemical properties and decay resistance of rubberwood by termites and fungi, Student Project, Prince of Songkla University, Thailand, 2011.

[3] S. Yaowalerd, W. Yingprasert, The investigation of bondability of rubberwood tapped by using ethylene gas, Student Project, Prince of Songkla University, Thailand, 2013.

[4] S. Khongao, A. Phetarwut, The penetration rate of boron compounds in ethylene stimulated rubberwood, Student Project, Prince of Songkla University Thailand, 2013.

[5] A. Dusotoit-Coucaud, P. Kongsawadworakul, L. Maurousset, U. Viboonjun, N. Brunel, V. Pujade-Renaud, et al., Ethylene stimulation of latex yield depends on the expression of a sucrose transporter (*HbSUT1B*) in rubber tree (*Hevea brasiliensis*), Tree Physiology 30 (2010) 1586-1598.

[6] R. Lacote, O. Gabla, J.M. Eschbach, F. Rivano, K. Dian, E. Gohet, Long-term effect of ethylene stimulation on the yield of rubber trees is linked to latex cell biochemistry, Field Crops Research 115 (2010) 94-98.

[7] T. Sainoi, S. Sdoodee, The impact of ethylene gas application on young-tapping rubber, Journal of Agricultural Technology 8 (4) (2012) 1497-1507.

[8] U. Silpi, P. Thaler, P. Kasemsap, A. Lacointe, A. Chantuma, B. Adam, et al., Effect of tapping activity on the dynamic of radial growth of *Hevea brasiliensis* trees, Tree Physiology 26 (2006) 1579-1587.

[9] D.C. Markstrom, A. Hann, Seasonal variation in wood permeability and stemoisture content of three mountain softwoods, Forest Service U.S. Department of Agriculture, 1972.

[10] M.R. Silva, G.O. Machado, J. Deiner, C.C. Junior, Permeability measurements of Brazilian *Eucalyptus*, Material Research 13 (3) (2010) 281-286.

[11] B. Cherdchim, N. Matan, B. Kyokong, Effect of temperature on thermal softening of black sweet-bamboo culms (*Dendrocalamus asper* Backer) in linseed oil, Songklanakarin Journal of Science Technology 26 (6) (2004) 855-866.

[12] F. Daudet, T. Améglio, H. Cochard, O. Archilla, A. Lacointe, Experimental analysis of the role of water and carbon in tree stem diameter variations, Tree Physiology 30 (2004) 1586-1598.

[13] M.S. Traore, M. Diarrassouba, K.M. Okoma, K.E. Dick, E.F. Soumahin, L.F. Coulibaly, et al., Long-term effect of different annual frequencies of ethylene stimulation on rubber productivity of clone GT1 of *Hevea brasiliensis* (Muell. Arg.) in South East of Cote d'Ivoire, Agricultural and Biology Journal of North America 2 (2011) 1251-1260.

[14] U. Junghans, R. Langenfeld-Heyser, A. Polle, T. Teimann, Effect of auxin transport inhibitors and ethylene on the wood anatomy of Poplar, Plant Biology 6 (2004) 22-29.

[15] C.H.A. Little, L. Eklund, Ethylene in relation to compression wood formation in *Abies balsamea* shoots, Trees 13 (1999) 173-177.