ACTA BIOLOGICA CRACOVIENSIA Series Botanica 49/1: 19–23, 2007

ANATOMY OF LEBANON CEDAR (*CEDRUS LIBANI* A. RICH.) WOOD WITH INDENTED GROWTH RINGS

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Received June 30, 2006; revision accepted January 30, 2007

This study examined the anatomical characteristics of indented growth rings in Lebanon cedar. In the indented pattern of growth rings, the alignment and shape of tracheids and rays were found to be irregular, and distinctive trabeculae were identified in tracheids. Multiseriate parenchymatic rays occur in addition to uniseriate and biseriate ones. In the indented pattern the average tracheid length is shorter, whereas the lumen diameter and double-wall thickness are wider than those of unindented ones. The average maximum ray height is greater than that of normal wood. The average number of tracheids per mm^2 differs only in latewood.

Key words: *Cedrus libani*, indented rings, tracheids, traumatic tissue.

INTRODUCTION

Among the conifers, the Cedar of Lebanon (*Cedrus libani* A. Rich.) is one of the most majestic. Its wood has been important commercially for millennia. Many ancient civilizations used its wood through the centuries in their homes, temples, sarcophagi and tombs (Kayacik and Aytug, 1968; Aytug and Gorcelioglu, 1987). It is native to Lebanon and to the Taurus Mts. of Syria and southern Turkey (Masri, 1995), but today its largest natural distribution is in the Taurus Mts. chain in the Mediterranean region of Turkey. A distinct relict population also occurs in northern Turkey near the Black Sea (Atalay, 1987; Ansin and Kucuk, 1990).

Knowledge of the anatomy of Lebanon cedar wood with normal structure comes from studies by various researchers (e.g., Greguss, 1955; Erdin, 1983; Fahn et al., 1986; Schweingruber, 1990; Cartwright, 2001). Specific figures in woods have been esteemed for their beauty and unusual structure for centuries (Beals and Davis, 1977). One of them, 'hazel' wood, is related to the presence of indented growth rings (Ziegler and Merz, 1961; Lev-Yadun and Aloni, 1991). This kind of wood may occur in many conifers including *Picea orientalis* Link., *P. abies* Karst., *P. sitchensis* Carr., *Pinus halepensis* Mill., *P. jeffreyi* Grev. & Balf., *Pseudotsuga menziesii* Franco, or *Thujopsis dolabrata* Siebold & Zucc. (Ziegler and Merz, 1961; Fukazawa and Ohtani, 1984; Schultze and Gotze, 1986; Lev-Yadun and Aloni, 1991; Sugawa and Fujii, 1992; Romagnoli et al., 2003). Some of them, such as spruce wood, are sought after for making musical instruments (Tsoumis, 1968).

Anatomical and physical characteristics of wood with indented rings have been investigated in some conifer species (e.g., Ziegler and Merz, 1961; Fukazawa and Ohtani, 1984; Ohtani et al., 1987; Lev-Yadun and Aloni, 1991). Structurally, the indented parts of growth rings of *Picea abies* (Ziegler and Merz, 1961), *P. sitchensis* (Ziegler and Merz, 1961; Fukazawa and Ohtani, 1984; Ohtani et al., 1987) and *Pseudotsuga menziesii* (Schultze and Gotze, 1986) are very different from normal wood in their shape, dimensions and cell alignment. Lev-Yadun and Aloni (1991) and Lev-Yadun (2000) examined growth ring indentations induced by artificial longitudinal scratches in the stems of *Pinus halepensis*. Sugawa and Fujii (1992) investigated unusual multiseriate rays of *Thujopsis dolabrata* with indented rings. Romagnoli et al. (2003) studied density variations in spruce wood with indented rings and showed that density was greater in indented than in unindented parts.

Indentations in growth rings also occur occasionally in the trunks of Lebanon cedar (Lev-Yadun, pers. comm.). The anatomical features of the wood in indented growth rings of this species are not covered in the literature. The aim of the present study is to fill this gap.

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PL ISSN 0001-5296

TABLE 1. Anatomical features of indented and unindented parts of growth rings in *C. libani* wood

	Normal growth ring Mean (min – max) ± sd	Indented growth ring Mean (min – max) ± sd	t-test Coefficients
TL	2.75 (1.45 – 3.44) ± 0.48	2.40 (1.41 – 3.67) ± 0.65	- 2.16*
TD_{ew}	29.40 (25 – 35) ± 2.63	35.40 (27.50 – 40) ± 3.36	7.03***
TD_{lw}	18.40 (15 – 22.50) ± 2.03	24.30 (20 – 30) ± 3.27	7.67***
DWT_{ew}	7.25 (5 – 8.75) ± 0.81	8.05 (5 – 10) ± 1.62	2.21*
DWT_{lw}	13.15 (11.25 – 15) ± 0.96	14.15 (10 – 18.75) ± 1.93	2.31*
TN_{ew}	840 (717 – 967) ± 71	890 (633 – 1183) ± 145	1.38ns
TN_{lw}	1778 (1366 – 2266) ± 227	1421 (1150 – 1850) ± 141	- 5.99***
RH_{max}	624.40 (560 – 690) ± 32.28	824 (680 – 1060) ± 99.87	9.51***
RN	8 (6 – 10) ± 1.07	8.05 (6 – 10) ± 0.99	1.15ns

*, ** and *** indicate the 0.95, 0.99 and 0.999 confidence levels, respectively.
TL – tracheid length (mm); TD_{ew} and TD_{lw} – tangential tracheid diameter in earlywood and latewood, respectively (μm); DWT_{ew} and DWT_{lw} – double wall thickness in earlywood and latewood respectively (μm); TN_{ew} and TN_{lw} – number of tracheids per mm^2 of earlywood and latewood respectively; RH_{max} – maximum ray height (μm); RN – number of rays per mm.

MATERIALS AND METHODS

A 5 cm thick wood disc was sampled at breast height from the trunk of a dominant individual of Lebanon cedar at 1750 m altitude on Elmali Mt., Antalya in 2005. The diameter at breast height of the sample tree was 35 cm, and it was approximately 120 years old. After cleaning the surface of the sample disc, two 1 cm^3 cubic subsamples were taken from both indented and unindented parts of the growth ring (total 4). To eliminate length-on-age influences, both indented and unindented samples were selected from the same growth ring (the year 2004).

In the laboratory the samples were boiled and placed in a solution consisting of equal parts of water, glycerine and ethyl alcohol for softening. Then, transverse, tangential and radial sections 15 μm, 15 μm and 20 μm thick, respectively, were taken with a Euromex sliding microtome. Routine procedures were followed for preparation of the sections and maceration (Yaltirik, 1971; Merev, 2003).

On each of the 4 different transverse, tangential and radial sections, 25 measurements were performed for the each of the following: tangential tracheid diameter, their double-wall thickness in earlywood and latewood, tracheid length, and maximum ray height. The number of tracheids per mm^2 of both earlywood and latewood (in transverse section) and the number of rays per mm (in tangential section) were determined by counting at twenty different points of each section.

The standard deviation and average of each quantitative feature and Student's t-test for equality of means were computed with the SPSS 10.0 program.

RESULTS AND DISCUSSION

In both indented and unindented patterns, growth ring borders are distinct, and the transition from earlywood to latewood is abrupt. Bordered pits in tracheids are generally uniseriate and very rarely biseriate. Pit apertures are circular to elliptic in earlywood, and slit-like in latewood. Some rays include marginal ray tracheids with smooth walls in a single file. Marginal and submarginal parenchymatic ray cells contain prismatic crystals, a well-known character of *Cedrus*. Cross-field pits are piceoid, cupressoid or taxodioid, and their number per field is 2–4.

Lebanon cedar wood with indented rings differs markedly from its normal wood in some qualitative and quantitative anatomical features. Individual indented rings line up radially in succession (Fig. 1), and in the examined wood specimen they reach the last ring without interruption from 1996 to the growth ring of 2005. For Sitka spruce, Fukazawa and Ohtani (1984) reported that some indented rings reached the cambium, while others vanished in the secondary xylem far from the cambium. In indented rings of Lebanon cedar the order of tracheids diverges from the usual radial orientation on transverse sections (Fig. 2). The tracheids at the indentations also deviate from longitudinal orientation, and they appear arched in radial section (Figs. 3, 4). Irregularly aligned and shaped tracheids in ring indentations were also reported by Fukazawa and Ohtani (1984), Ohtani et al. (1987) and Lev-Yadun and Aloni (1991). Trabeculae are more clearly evident in the tracheids of indented than unindented parts of Lebanon cedar rings (Fig. 5), and they are more frequent than in normal wood.

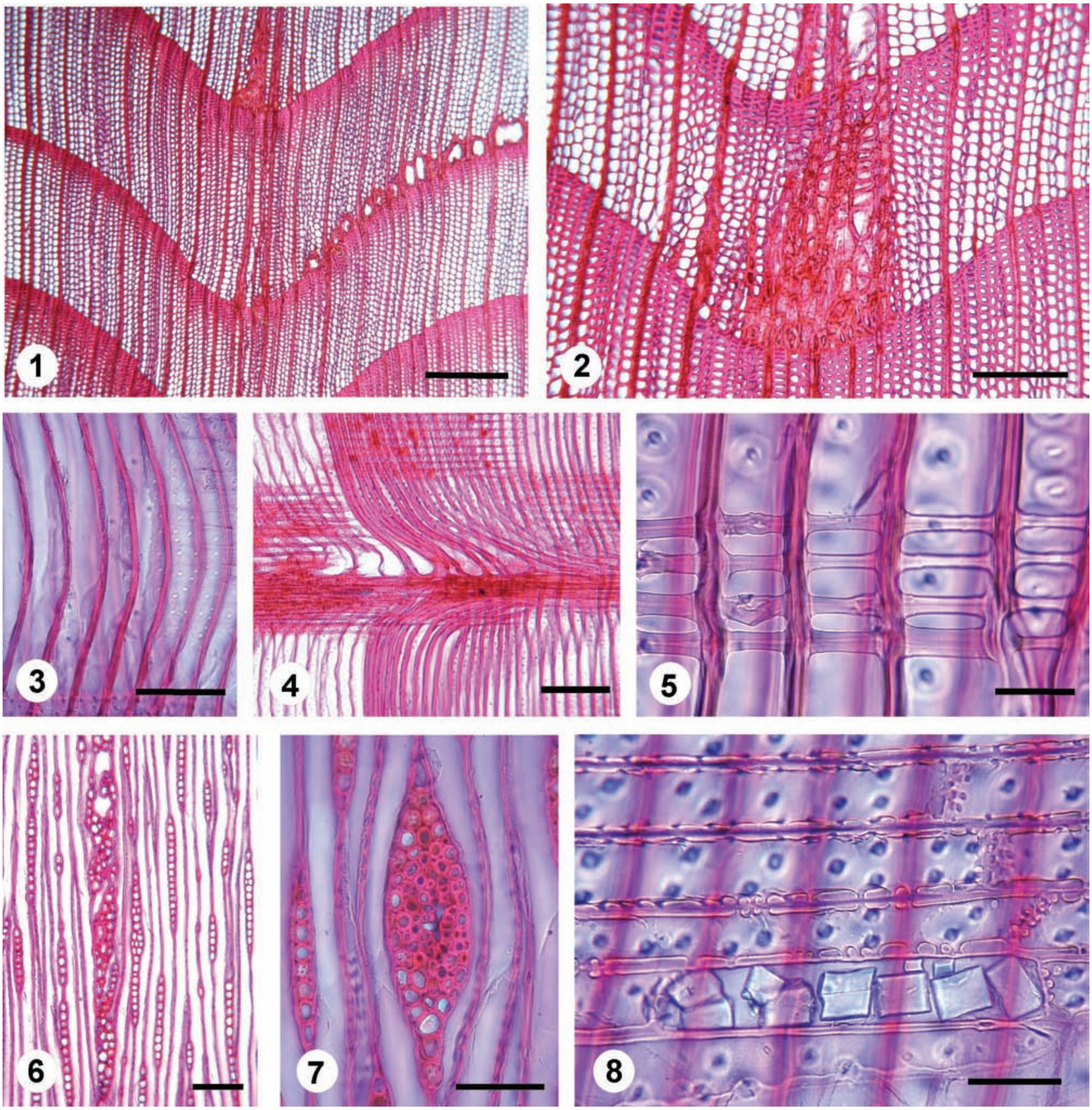

Fig. 1. Indented rings and axial traumatic resin canals in transverse section. Bar = 500 μm. **Fig. 2.** Tracheids diverging from the usual radial orientation in transverse section. Bar = 250 μm. **Fig. 3.** Tracheids diverging from the usual longitudinal orientation in radial section. Bar = 100 μm. **Fig. 4.** Growth ring border at indentation in radial section. Latewood tracheids diverging from the usual longitudinal orientation. Bar = 200 μm. **Fig. 5.** Trabeculae in tracheids in radial section. Bar = 30 μm. **Fig. 6.** Rays in tangential section. Bar = 150 μm. **Fig. 7.** Multiseriate ray in tangential section. Bar = 90 μm. **Fig. 8.** Prismatic crystals in parenchymatic ray cell in radial section. Bar = 30 μm.

Similarly, Ohtani et al. (1987) reported that in Sitka spruce the tracheids of indented rings commonly have trabeculae. Grosser (1986) found trabeculae in large numbers in association with wound tissue. The indentations of growth rings in Lebanon cedar are generally associated with aggregate rays (Fig. 6), as Sugawa and Fujii (1992) saw in *Thujopsis dolabrata*. While the rays in normal wood of *C. libani* are mostly uniseriate and rarely biseriate, the indented parts of its growth rings show (rarely) multiseriate rays in addition to uniseriate and biseriate ones (Fig. 7). Marginal and submarginal ray cells in indented rings commonly have many prismatic crystals (Fig. 8). Prismatic crystals are more or less common in the marginal and submarginal ray cells of some species of *Cedrus* (IAWA Committee, 2004). In the indented parts of growth rings in the examined Lebanon cedar wood, only one indented ring had axial traumatic resin ducts (Fig. 1). Lev-Yadun and Aloni (1991) reported that tissues formed from vascular cambium of *P. halepensis* after wounding have many very large resin ducts in addition to the normal-sized ones, a well-known phenomenon in pines (Fahn, 1979).

According to the t-test for equality of means, in indentations the average diameter, length and double-wall thickness of tracheids, and average maximum ray height differed significantly from the values for unindented parts of growth rings. While average tracheid length was lower in indentations ($p < 0.05$), lumen diameter ($p < 0.01$) and double-wall thickness ($p < 0.05$) were wider than in unindented parts. The average maximum ray height in indented rings was higher than in unindented ones ($p < 0.01$). The number of tracheids per mm^2 differed only in latewood of indented rings ($p < 0.01$). For the quantitative parameters examined, Table 1 shows significant and non-significant differences between indented and unindented parts of growth rings in Lebanon cedar wood.

The range of measured values for indented parts of growth rings was wider for unindented parts, except for number of tracheids per mm^2 in latewood, and for number of rays per mm (Tab. 1). For tracheids in normal wood of Lebanon cedar from the Taurus Mt. chain, Erdin (1983) gave the following average values: length 3.2 mm, width 32.2 µm in earlywood and 24.2 µm in latewood, and double-wall thickness 4.6 µm in earlywood and 11.2 µm in latewood. Average tracheid length in various archeological specimens of Lebanon cedar wood was found to be 4.3 mm (Kayacik and Aytug, 1968), and 3.2 mm in earlywood and 3.5 mm in latewood (Babos and Voros, 2001). In the present study, average tracheid dimensions in normal wood of Lebanon cedar were 2.7 mm length and 29.4 µm width (earlywood) or 18.4 µm width (latewood). The double-wall thickness was 7.2 µm in earlywood and 13.1 µm in latewood. In indented rings, the average tangential diameter of irregularly shaped tracheids was 35.4 µm in earlywood and 24.3 µm in latewood. The average double-wall thickness of these tracheids was 8.0 µm in earlywood and 14.1 µm in latewood. The average tracheid length was 2.4 mm for earlywood and latewood taken together. The tracheids in the indented parts of growth rings were shorter but slightly wider than those in Erdin's (1983) normal wood, and their walls were also wider. Similar findings on shorter and wider tracheids in indented rings also appear in other conifer species; Lev-Yadun and Aloni (1991), however, reported shorter and narrower tracheids in indented rings of *Pinus halepensis.* Fukazawa and Ohtani (1984) reported shorter and wider tracheids in indented growth rings of spruce wood, and pointed to the similarity of these short, wide and irregularly formed tracheids to vasicentric tracheids in hardwoods. Schultze and Gotze (1986) found that tracheids in hazel-grained spruce and Douglas fir were on average shorter than those in their normal wood, and suggested that it was probably related to the hypertrophied ray parenchyma in tangential sectors of decreased increment. Ziegler and Merz (1961) reported that ray volume is 15–20% greater in indented than in normal parts of growth rings. For *P. halepensis*, Lev-Yadun and Aloni (1991) showed that the tissues formed after artificial scratches were made in its trunk have more rays. Average maximum ray height is greater in indented than in unindented growth rings of Lebanon cedar; in consequence, ray volume probably is greater as well.

Ziegler and Merz (1961) suggested that indentations in growth rings are due to local growth disturbances in the cambium, but Tsoumis (1968) indicated that the cause was not known. Schultze and Gotze (1986) suggested that hazel-grain in wood is due to endogenous (possibly genetic) factors. Lev-Yadun and Aloni (1991) experimentally showed that artificially scratched parts of the cambium in *Pinus halepensis* produce indentations in growth rings. Lev-Yadun (2000) maintained that indented rings may form for at least 8 years after artificial wounding.

Experimental studies by Lev-Yadun and Aloni (1991) have led to the production of various coniferous woods with indented rings, which are in demand for commercial use. Though the anatomical characteristics of indented patterns are usually similar in every coniferous species considered, Lebanon cedar trunks subjected to artificial scratching should be investigated with regard to the anatomical, physical and chemical characteristics of indented rings, and especially to hormonal disturbances in the vascular cambium.

ACKNOWLEDGEMENTS

I wish to thank Prof. Dr. Simcha Lev-Yadun of the Department of Biology, Faculty of Science and Science Education, University of Haifa-Oranim, for very helpful criticism.

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