

Wood quality – what can we learn from cell-wall chemistry?

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Abstract

Compression wood is chemically different from normal, opposite and flexure wood. Based on these chemical differences, we have investigated several techniques that could potentially be developed into methods that could be used in commercial situations to identify and segregate compression wood. The leading contender is near infrared spectroscopy.

Introduction

Foresters are aware that radiata pine plantations grown for longer periods produce stiffer, more stable wood. Yet, there are increasing financial incentives to harvest plantations earlier, resulting in wood of poorer quality. This problem arose from radiata pine breeding focusing on form and growth rate, with little attention given to wood quality (Walker, 2013). To address this, the University of Canterbury and the University of Auckland collaborated on a project with two broad aims.

The first aim was to select, at an early age, radiata pine clones and families with superior wood qualities, i.e. longitudinal stiffness (elastic modulus) and longitudinal dimensional stability. The second aim was to understand the chemical reasons for high

longitudinal dimensional instability and, based on this chemistry, to devise practical ways of finding wood with dimensional instability. Some of the selection work has been described (Apiolaza et al., 2011, 2011a, 2013; Chauhan et al., 2013). Here we describe the results of the second aim concerning the chemical studies.

Different wood types

Does the wood of sapling trees grown upright, tilted or swayed differ in stiffness, dimensional instability and chemistry? Sapling radiata trees were grown either upright, tilted at 45° to the vertical (Figure 1), or swayed on a specially built rocking machine that simulates the trees swaying in wind. The tilted saplings developed severe compression wood on the undersides of their stems. This was evident by the dark reddish coloration of the wood (Figure 1), although wood coloration is not a reliable guide to the presence of compression wood and the chemical reasons for this coloration are unknown (Timmell, 1986).

The tilted trees developed another type of wood, referred to as opposite wood, on the opposite side of the stem, which was separated from the compression wood by cutting. Opposite wood shows anatomical similarities to the wood of trees growing upright, i.e. to normal wood. Trees that sway to and fro in the wind are known to develop a special type of wood referred to as flexure wood (Telewski, 1989). This can show some anatomical features of compression wood, but little research has been done on its chemical composition.

Stiffness

The seedlings were grown for eight months before testing. All four wood types had low longitudinal stiffness (elastic modulus), which confers flexibility to the sapling stems, allowing them to sway in the wind. This stiffness is related to the structure and chemistry of the wood cell walls. In softwoods, such as radiata pine, most of the wood cells are of a cell type known as a tracheid. When fully formed, these have thick walls mostly consisting of a secondary wall with three layers known as S1, S2 and S3 (Dinwoodie, 1975; Harris & Stone, 2008). These walls contain thin strands (microfibrils) made up of cellulose, which is a polymer of the sugar glucose. In contrast to the thinner S1 and S3 layers, the cellulose microfibrils of the S2 layer all have the same orientation and the angle of these relative to the cell axis is the microfibril angle. Importantly, this angle is inversely related to longitudinal stiffness (Cave, 1968).



Figure 1: Radiata pine saplings growing tilted. Insets show the compression (darker coloured) and opposite wood types that develop

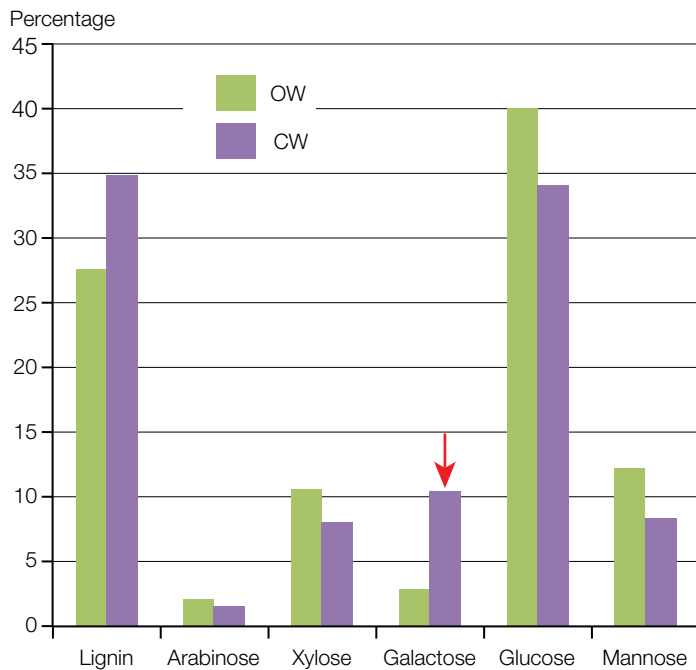


Figure 2: Chemical compositions of opposite (green) and compression (purple) woods. Red arrow indicates the much higher galactose content of compression wood

Instability

The longitudinal dimensional instabilities of the normal, compression, opposite and flexure woods were determined by rewetting after drying. Interestingly, only compression wood was different. It swelled three times more than the other wood types. In addition to low stiffness, high microfibril angles are associated with high dimensional instabilities (Meylan, 1968). However, high microfibril angles are not sufficient for swelling (or shrinkage) to occur, and other components of the tracheid walls besides cellulose must be involved.

Wet chemical analyses

The chemical compositions of the four wood types were examined using traditional wet chemical techniques (Brennan et al., 2012). In wood cell walls, the cellulose microfibrils are embedded in a complex mixture of polymers including other sugar polymers (polysaccharides), sometimes known as hemicelluloses, as well as lignin, an aromatic polymer that is made up of phenolic units containing benzene rings. The wall polysaccharides were analysed by breaking the links between the individual sugars. The different sugars released were then separated and quantified. Much of the glucose released was from cellulose, but other sugars were from the various hemicelluloses. These sugars included arabinose, xylose, galactose and mannose.

Interestingly, the compression wood differed markedly from the other wood types in the percentages of the different sugars released (monosaccharide composition) (Figure 2). Compression wood yielded three times more galactose than the other wood types, which did not differ

significantly. Moreover an earlier wet chemical study on butt logs from a 24-year-old plantation of loblolly pine (*Pinus taeda*), a species closely related to radiata pine, also implicated a galactose-containing polysaccharide in longitudinal instability (Floyd, 2005). The lignin content of the radiata wood types was determined and again the compression wood stood out; it contained more lignin than the other wood types, which had similar lignin contents to one another (Figure 2).

Using nuclear magnetic resonance spectroscopy

The fine detail about the different wood types, especially about the galactose-containing polysaccharide and the lignin in the compression wood, was obtained by nuclear magnetic resonance (NMR) spectroscopy using a technique pioneered by Professor John Ralph (a New Zealander, ex FRI) of the University of Wisconsin, Madison, in the United States (Kim & Ralph, 2010). This technique gave finger prints for the different wood types and showed two very distinctive differences in the compression wood:

- First, the galactose-containing polymer is a (1→4)-β-galactan that occurs in far larger proportions in compression wood. This polysaccharide is made up of long chains of galactose molecules, each being joined to the next through the hydroxyl group on carbon four. It is a flexible polysaccharide shaped like a wire spring and is known to absorb water and swell (Rees & Scott, 1971). It could, at least in part, account for the instability of compression wood. The peaks produced by this polysaccharide are larger in the finger prints of compression wood than the other wood types (Figure 3)
- Second, the lignin in compression wood contains small amounts of *p*-hydroxyphenyl units (H-units), which are not found in the lignin of the other wood types.

Locating the (1→4)-β-galactan in the tracheid wall

The exact location of the (1→4)-β-galactan in the tracheid walls of the compression wood was determined by using a particular type of monoclonal antibody (LM5) produced by Professor Paul Knox and his colleagues at the University of Leeds in the United Kingdom and which binds only to (1→4)-β-galactans (Jones et al., 1997). Thin sections of wood were treated with this antibody (primary antibody) and then with a second antibody (secondary antibody), which is labeled with a very small gold particle (colloidal gold), and which binds specifically to the primary antibody (Figure 4).

The section was then examined in a transmission electron microscope. The gold particles appear as black dots and reveal the locations of the (1→4)-β-galactans (Altaner et al., 2010). This showed they were in the outer part (away from the cell lumen) of the S2 layer (Figure 5), a region known to contain a high concentration of lignin (Donaldson & Singh, 2013).

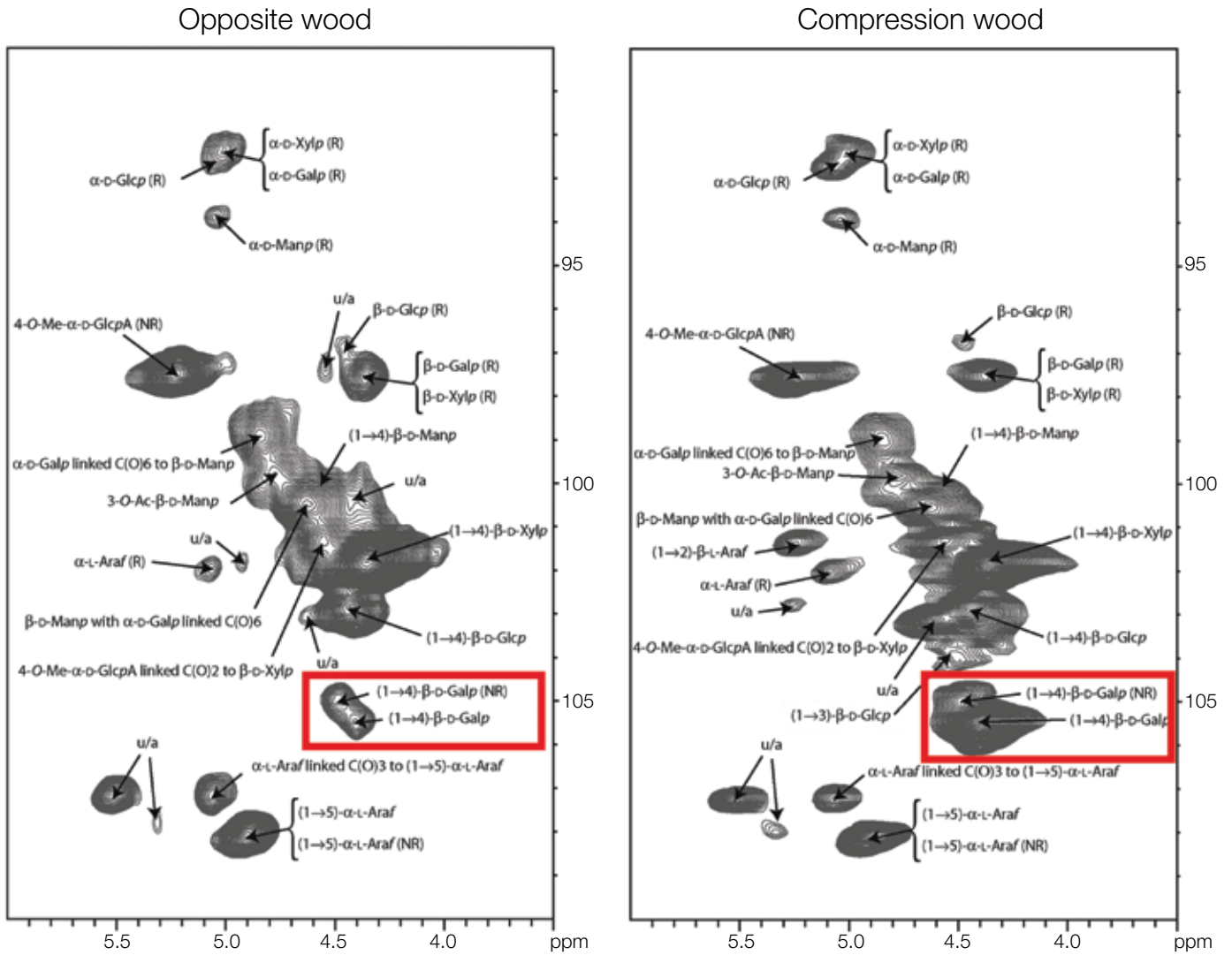


Figure 3: NMR finger prints of opposite and compression woods. Boxes are around peaks due to (1→4)-β-galactans, which are larger in the compression-wood finger print

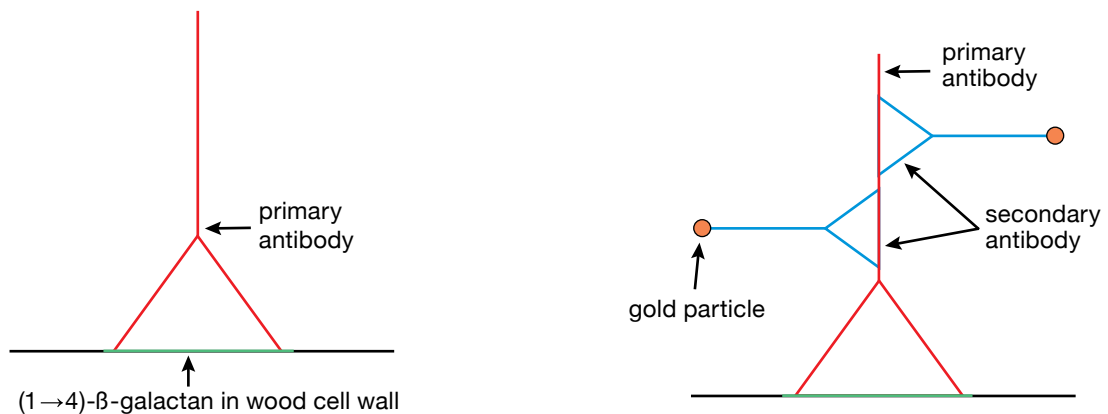


Figure 4: Principle involved in locating (1→4)-β-galactans in tracheid cell walls using the monoclonal antibody LM5 (primary antibody) and secondary antibodies labeled with gold particles

What does this mean for foresters?

Clearly compression wood is very different from normal, opposite and flexure wood. Based on these chemical differences, we have investigated several techniques that potentially could be developed into methods that could be used in commercial situations to identify and segregate compression wood. The techniques include a method based on the LM5 antibody (immuno-dot assay method) (Chavan et al., unpublished), a method based on heating wood in the absence of air and analysing the fragments (pyrolysis gas-chromatography mass spectrometry) (Brennan et al. 2014), and two types of spectroscopy (McLean et al., 2014):

- Attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR)
- Infrared (NIR) spectroscopy.

Although they vary in cost and speed, all of these methods were successfully used to identify compression wood, and all could be used for breeding trials. However, where speed and on-site availability are crucial, such as in saw mills, the leading contender must be NIR spectroscopy. Although considerable challenges remain before it can be implemented commercially (Harris & Altaner, 2013), we have reasons for being optimistic. NIR is installed in-line on the live-chain in meat works (Reis, 2013) and Solid Wood Innovation has trialled the technology for two wood-based applications:

- Rejecting resinous wood in appearance manufacturing
- As one sensor in a multi-sensor segregation system for lumber based on its propensity to warp in service.

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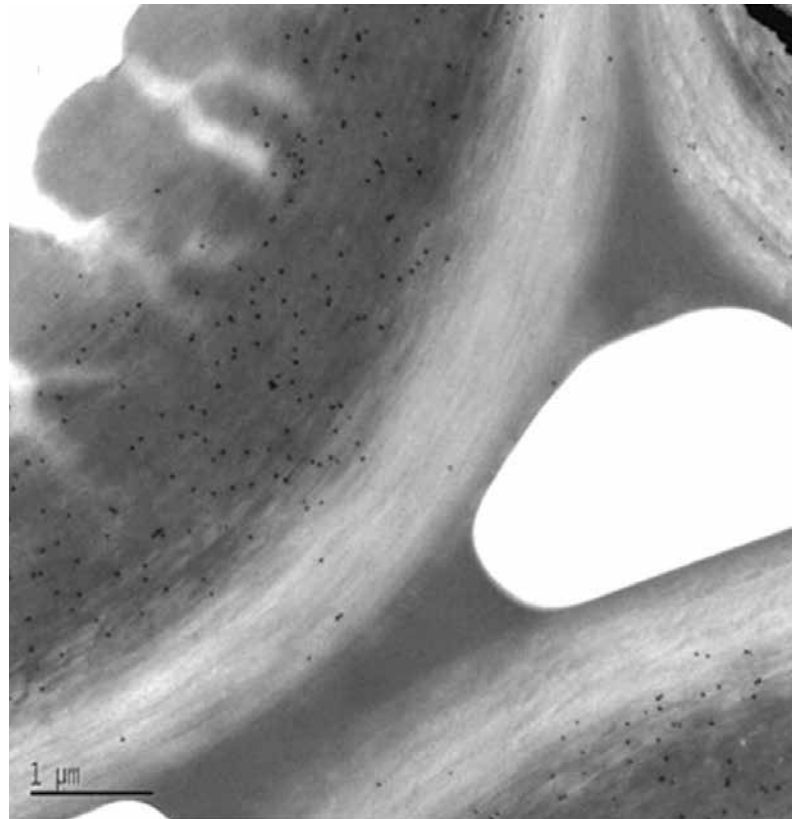


Figure 5: Location of (1→4)-β-galactans (black dots) in the outer part of the S2 layer of the wall of a compression wood tracheid

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