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Longitudinal Penetration of Water through the Vessel and Wood Fiber in *Castanea crenata*[1]

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ABSTRACT

An experiment was conducted to know ultra-pure distilled water penetration depth through large vessel, small vessel, latewood fiber and earlywood fiber in longitudinal direction of *Castanea crenata*. In heartwood, latewood fiber transported water more than large and small vessel. While in sapwood, small vessel conduction depth was found the highest. Penetration depth of water after 15.0 seconds, no significant difference was observed among earlywood fiber, latewood fiber and earlywood vessel. Whilst in heartwood, no statistical difference was observed among earlywood fiber, latewood fiber and earlywood vessel. At the beginning, the speed of water penetration was high and then gradually decreased.

Key words: Water penetration, longitudinal penetration, surface tension.

INTRODUCTION

Since the structure of vessels facilitates longitudinal liquid flow in the living tree, it is not surprising that vessels play a primary role in liquid penetrability (Ahmed and Chun 2007; Choi et al. 2007). However, their effectiveness is dependent upon size, number and distribution and even more importantly upon the extent of extraneous materials and tyloses present as well as upon the character of pitting that leads to contiguous cells. The factors emphasized in this study tyloses, pittings and anatomical features. Although fiber often constitutes the bulk of woody tissues, in general they are not considered to be as important as vessels in initial liquid penetration. However, their permeability may have a decided influence on the subsequent spread of liquid from vessels. Compared to vessels, fibers with their thick cell walls and irregular distribution of relatively small pits do not appear especially adapted for liquid conduction. Since liquid flow between fibers is dependent primarily upon pits, these structures were also examined.

The objective of this paper is to describe the longitudinal penetrability of *Castanea crenata*. Though the penetration of liquid is the combined effect of flow and diffusion, only capillary flow in vessel and wood fiber of *Castanea crenata* was considered for measuring the penetration depth at different time sequence. Depending on cell structure, the penetration depth differences of water in vessel and in wood fiber were explained. This result will help us to compare the permeability differences in *Castanea crenata* while using different liquids.

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MATERIALS AND METHODS

Sample preparation and penetration depth measurement

Wood samples of *Castanea crenata* Sieb. et Zucc. were obtained from Jiamri, Sabukmeyeon, Chunchon, Kangwon-do, Republic of Korea. Samples ere collected from a defect-free tree and discs were made. Liquid penetration was observed from top and bottom end direction. Sample size and method of liquid penetration measurement was done by following same methodology mentioned by (Ahmed et al. 2007).

Liquid

In this experiment, ultra-pure distilled water was used for measuring the penetration depth. Ultra-pure distilled water was collected from Water Purification System- Scholar, Next Power 1000. Its density was 0.9973 g/cc and surface tension was measured to 71.88 dyne/cm at 24 ^{0}C.

Statistical analysis

Water penetration depth differences in different cells were analyzed by using a one-way ANOVA. When significant differences occurred ($P \leq 0.05$), the ANOVA procedure was followed by a Duncan significant difference post hoc test to separate the cell effects on water penetration depth variation (SPSS, Version 12.0.1, 2003).

RESULTS AND DISCUSSION

Microscopic characteristics of vessel and wood fiber of *Castanea Crenata* was found like distinct growth ring boundaries, ring-porous, vessel arranged in dendritic pattern with simple perforations, vessel-ray pits with much reduced borders to apparently simple; pits rounded or angular, tyloses common in vessel, non-septate fiber with simple to minutely bordered pits.

The permeability to water of wood cell wall material has importance in studies of the treatment of wood with aqueous solutions, such as water-borne preservatives, and also in investigations of the movement of water in the living tree. It has been suggested that aqueous preservative solutions may flow through cell walls by way of cell wall capillaries (Bailey and Preston 1970). In reviewing water transport in plants, Jarvis (1975) has pointed out the importance of water movement through cell walls in roots and leaves and the lack of direct measurements of cell wall permeability. Although axial flow of water in the stem of the living tree occurs through cell cavities and pits some lateral flow may occur through cell walls. This flow of liquid in wood also dependent on the moisture content of wood. Moisture content of *Castanea crenata* was recorded in sapwood 29.1% and in heartwood 27.9%. In this moisture level water penetration depth are presented below.

Table 1. Water penetration depth of sapwood in longitudinal direction unit: μm

Cell type	3.8 Second	7.5 Second	11.3 Second	15.0 Second
Fiber in earlywood	426.40b	462.29b	507.75b	526.61b
Fiber in latewood	430.41b	466.06b	505.26b	529.95b
Vessel in earlywood	436.76b	460.23b	495.91b	528.07b
Vessel in latewood	547.39a	779.03a	960.59a	1045.98a

Note: Different lower case letters within in a column indicate significant difference (≤ 0.05).

Table 2. Water penetration depth of heartwood in longitudinal direction unit: μm

Cell type	3.8 Second	7.5 Second	11.3 Second	15.0 Second
Fiber in earlywood	231.82a	320.31ab	395.17a	469.72a
Fiber in latewood	236.12a	342.33a	414.60a	482.13a
Vessel in earlywood	177.66b	214.40a	237.92c	258.24b
Vessel in latewood	205.06ab	304.04b	338.41b	371.71a

Note: Different lower case letters within in a column indicate significant difference (≤0.05).

In this experiment we found that latewood penetration depth of water was 1.31 times higher than in earlywood penetration. Vessel in earlywood had the lower penetration depth than that of wood fiber. In heartwood, fiber present in earlywood had higher penetration depth than large vessel.

The penetration of hardwoods with water varies greatly between sapwood and heartwood. Axial penetration is mainly conducted by vessel along with wood fiber. In this experiment we found that water penetration depth in vessel was higher than wood fiber especially in earlywood. This is because the narrow cell lumen has higher capillary pressure (Chun and Ahmed 2006). Heartwood water penetration depth was found low due to presence of tyloses. In other word, tyloses and various gummy, resinous and chalky exudates often form in heartwood (Hillis 1987) and formation of this material reduces the treatability of heartwood (Kumar and Dobriyal 1993). Teesdale and MacLean (1918) found that the treatability of hardwood was directly related to whether the vessels contained tyloses and if tyloses were present the completeness of the vessel blockage by the tyloses. A practical example of the role of tyloses in blocking fluid flow is the use of white oak to make barrels for wine and whisky (Cote 1990). It worth nothing that since the tyloses and extractives are more likely to be found in the heartwood (Panshin and deZeeuw 1980), one would expect that these factors are responsible for the reduction of the heartwood treatability. In other words, the tyloses in *Castanea crenata* heartwood are virtually impenetrable. As a result, sapwood was found more permeable than heartwood and water penetration depth in sapwood was 1.7 times higher than in heartwood.

Fiber occupies about 25 to 75% respectively of the total volume of hardwoods (Wang and DeGroot 1996). When the vessels are occluded with tyloses and extractives, the literature seems to indicate that fiber could function as fluid conducting channel. In this experiment we found that when the heartwood vessel was occluded with tyloses, fiber played an important role for water penetration and it was about 1.5 times higher. In this case, earlywood vessel conducted the lowest amount of liquid and the difference was found significant. Conduction of earlywood fiber, latewood fiber and latewood vessel were statistically found the same. Furthermore, latewood was found more permeable than earlywood. Overall water penetration depth in latewood was higher than earlywood by 1.31 times. It may due to the fact that the lumen diameter in latewood is narrower than in earlywood. For the same reason, water penetration depth in small vessel was found higher than large vessel elements. More specifically, latewood fiber and vessel present in sapwood, conducted water1.5 times higher than that in earlywood whilst it was about 1.2 times higher in heartwood. Anatomical features are same for sapwood and heartwood. But for the micro structural differences from earlywood to latewood, different penetration results were observed. So, in the same wood species, the penetration of water was differed from sapwood to heartwood and earlywood to latewood.

From the Figures 1 and 2, it is clear that after 15.0 seconds of penetration in longitudinal direction, water penetration depth was the highest in sapwood fiber whilst heartwood vessel conducted the lowest. In sapwood, no statistical difference of water penetration depth was observed among fiber in earlywood, fiber in latewood and vessel in earlywood. Large vessel in heartwood had the lowest penetration depth of water and the reason of it's lower permeability was discussed earlier. Furthermore, surface tension of liquid also and important factor which determines the penetration depth in wood (Chun and Ahmed 2006). Lower the surface tension, higher the capillary rise. In this experiment the surface tension of ultra-pure distilled water was found 71.88 dyne/cm at 24^{0}C. The penetration depth is thought to be low in this species at same moisture content level if we use the other liquid which has higher surface tension than water. This is why, water penetration depth in this experiment was found lower than essential oil which is described elsewhere (Ahmed et al. 2008).

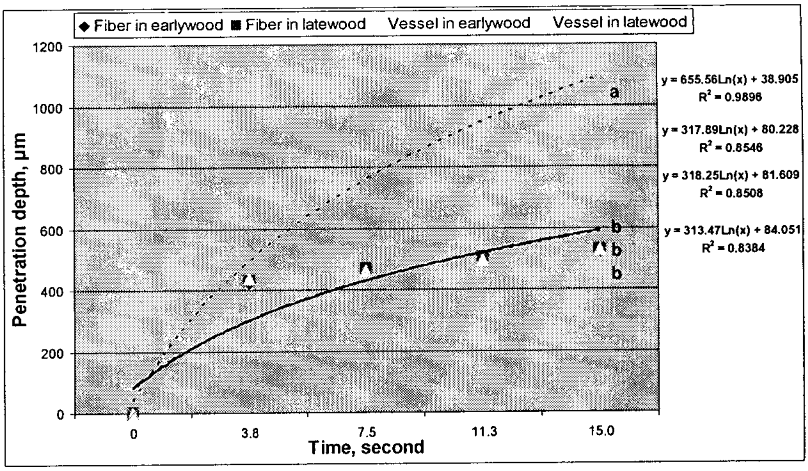

Fig.1. Line graph showing water penetration depth in sapwood.

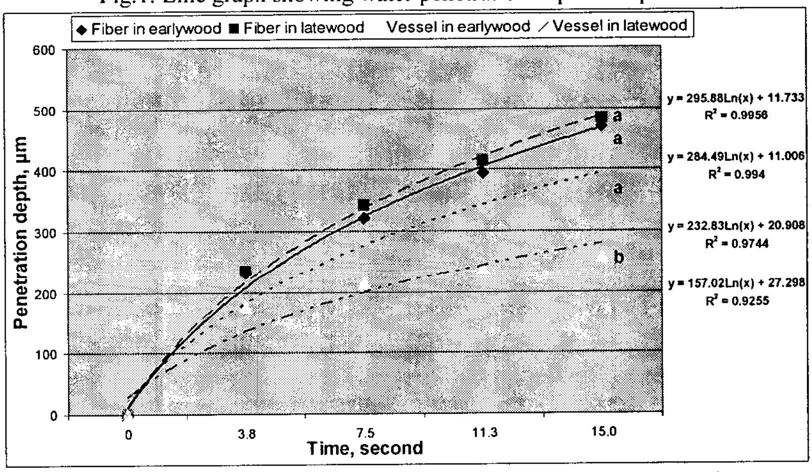

Fig.2. Line graph showing water penetration depth in heartwood.

Water penetration rate was found high at the beginning and then gradually decreased. After 3.8 second of penetration, water penetration depth decreased upto 80% at 7.5 second, 87% at 11.3 second and 91% at 15 second. It meant that liquid flow decreasing rate was not found in even rate. We can make conclusion from this result that, liquid flowing in longitudinal direction followed a go-stop-go cycle until and unless the capillary pressure of water created by cell lumen is equal to pressure of air above the air-water interface. In this case the penetration is likely to be stopped. The rate of flow of liquid into the lumen of the fibers and vessels must thus control the rate of take up of liquid over the time range.

CONCLUSIONS

Ultra-pure distilled water penetration depth was found higher in sapwood compared to heartwood. Latewood penetration was found higher than in earlywood. In heartwood, fiber played an important role for water penetration and the penetration depth was about 1.5 times higher than vessel. Small vessels in sapwood conducted water significantly the highest whilst large vessel conducted the lowest in heartwood. Initially water penetration speed was found high and then gradually decreased in an uneven rate.

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