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Flow Behavior of Safranine Solution in *Prunus sargentii* Rehder[1]

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ABSTRACT

An experiment was conducted to compare the 1% safranine solution flow depth in radial and longitudinal direction of *Prunus sargentii*. Longitudinal flow of safranine solution was found higher than radial flow. Body ray parenchyma was found more permeable than marginal ray parenchyma and it was about 1.3 times higher. Intercellular space conducted safranine solution more than ray parenchyma. Vessel was found to be the main avenue for liquid conduction in longitudinal direction. Different anatomical features of ray, vessel and fiber affected the penetration depth of safranine solution. Moreover initial penetration depth was found to be high and thereafter decreased gradually.

Key words: Liquid penetration, Axial flow, Radial flow, Surface tension.

INTRODUCTION

Different techniques and methods are used to observe the liquid penetration behavior in wood (Ahmed et al. 2007; Ahmed and Chun 2007; Chong et al. 2007; Choi et al. 2007; Chun and Ahmed 2007). Different techniques and methods are used for measuring liquid penetration in wood. Bao (1984) stated that it differs from species to species and that there are large differences among different families, genera and even within parts of the same tree. The movement of liquid flow in wood is highly complicated by the fact that passage occurs through structures varying in size from vessels, down to passages of molecular size through the cell walls. Both liquids and vapors can move through the coarse capillary structure under two different means of motivation that follow different laws, namely by pressure permeability and by diffusion (Stamm and Raleigh 1967). Vessels, fiber and ray parenchyma, axial parenchyma are all tubular in nature and can properly be referred to as capillaries with some minor imperfections.

Through capillary, the solution impregnation is not also same in longitudinal and lateral direction. Penetration also differs from sapwood to heartwood, contact angle, molecular weight and surface tension of liquid being used. In this experiment we used safranine solution. Actually this kind of solution is used for staining in microscopic observation. As the solution is red in color, it will be easy to observe the safranine solution flow depth in wood. This paper explains about the safranine solution flow in radial and longitudinal direction of *Prunus sargentii*, also about the reason of safranine solution penetration depth difference from other previous experiments.

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MATERIALS AND METHODS

Sample preparation

Wood samples of *Prunus sargentii* Rehder were obtained from Jiamri, Sabukmeyon, Chunchon, Kangwon do, Republic of Korea. Immediately after sample collection from defect free tree, discs were made and marked to identify top and bottom end. Discs were kept in an air-tight cellophane bag to protect the moisture loss. To observe the longitudinal safranine solution flow in tangential surface- 4 cm (long) x 1 cm (tangential) x 0.5 cm (radial) and to observe the radial flow- 4 cm (long) x 1 cm (radial) x 0.5 cm (tangential) were prepared after microtome shaving. In longitudinal penetration, flow was observed from bottom to top direction and for radial penetration flow was observed from bark to pit direction. 3 replications were done be dividing sapwood and heartwood in each direction. Except one cross and tangential surface for longitudinal and one radial and tangential surface for radial penetration, all surfaces were coated with silicon resin for preventing the leakage by other surfaces.

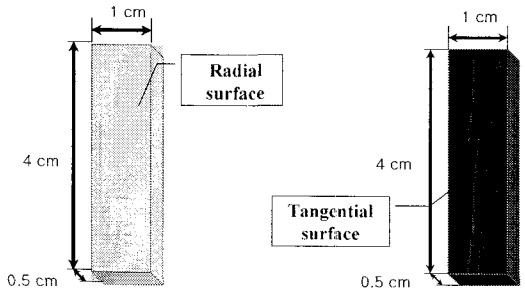

Fig.1. Sample size for measuring a safranine solution flow depth in radial (left) and longitudinal direction (right).

Estimation of moisture content

Wood sample were weighed and dried in an oven for 24 hours at 105 ^{O}C. Moisture content of wood block in terms of wet weight basis was calculated.

Preparation of safranine solution (1%)

10 g of safranine was taken in 1 L of volumetric flask and 500 mL 50% ethyl alcohol was added. Distilled water was added to make the volume 1000 mL.

Camscope observation

During the observation of safranine solution flow, the room temperature was 24 ^{0}C, RH 60% and the wind speed was 0 m/s. Coated samples were fixed on a petridish and safranine was poured on it. With *i*-Solution software, the safranine solution impregnation video file was captured by *i*-camscope (SV32) for about 5 minutes. The captured 5 minutes video file was divided in specific frames at 3.76, 7.52, 11.28 and 15.04 second for longitudinal direction and frames at 18.8, 37.6, 56.4 and 75.2 for radial direction by VitrualDub-MPEG2 software.

Statistical analysis

Safranine solution flow differences different cells and direction were tested 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 time and cell effects (SPSS, Version 12.0.1, 2003).

RESULTS AND DISCUSSION

Prunus sargentii was characterized mostly by distinct growth ring boundaries, diffuse-porous, simple perforations, alternate non-vestured intervessel pits, and helical thickenings throughout body of vessel elements. Thin to thick walled non septate fibers with simple to minutely bordered pit which mainly confined in radial wall. Axial parenchyma scanty paratracheal and also scanty diffuse. Larger rays commonly 4 to 5 seriate are dominantly present where body ray cells are procumbent with mostly two to four rows of square marginal cell.

It is proved that moisture content plays an important role for the liquid impregnation. Above the fiber saturation point until the cell cavity are filled with liquid water, wood can still take up water by absorption or capillary action (Browning 1963) while the permeability of some wood species decrease with an increased moisture content (Comstock 1968). Moisture content of *P. sargentii* was found in sapwood 28.02% and in heartwood 25.0%. The flow depths in radial and longitudinal direction were presented in Table 1 and Table 2.

Table 1. Safranine solution flow depth in radial direction unit: μm

Cell type	Sapwood				Heartwood			
	18.8 Second	37.6 Second	56.4 Second	75.2 Second	18.8 Second	37.6 Second	56.4 Second	75.2 Second
Body ray cell	40.01b	44.45b	47.97b	52.49b	30.47b	35.28b	42.22b	47.44b
Marginal ray cell	31.51b	38.86b	41.68b	47.33b	21.81b	23.34b	25.43b	27.92b
Intercellular space	61.26a	95.43a	114.89a	133.47a	64.90a	71.69a	90.62a	96.36a

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

Ray cells are connected together end to end to form a tubular structure which act as capillary. Through this capillary radial conduction is done by ray parenchyma. In ray parenchyma endwall has pit through which liquid can pass through. Not only endwall pit but also there are numerous lateral wall pits in ray parenchyma which interconnect them in a net like structure. As a result, ray cells acts as an important channel in radial conduction. This conduction can vary from earlywood to latewood, juvenile to matured wood and sapwood to heartwood. In heartwood usually conduction is low because of its reduced conductive ability. In this experiment we found that sapwood penetration depth was 1.36 times more than that of heartwood. Also the safranine penetration depth differences were not in same for body and square marginal ray cells. Overall body ray cells permeability is higher than marginal ray cells and it was about 133% high. Wood cell lumen diameter is an important factor for the liquid conduction which was reported by Chun and Ahmed 2006. They explained that if the cell lumen diameter was narrow than it will create a high capillary pressure compared with the wider one, consequently high force enables the liquid to penetrate deeper. Our experiment also supports their results. In *Prunus sargentii*, body ray parenchyma length 40.07μm (SD: 9.67, range: 26.14-66.94μm), diameter 11.01μm (SD: 3.43, range: 5.09-18.61), endwall pit number 14 (SD: 2.34, range: 11-17) and marginal square ray cell length 23.02μm (SD: 4.81, range: 11.78-29.60μm), diameter 15.56μm (SD: 4.57, range: 7.76-23.16), endwall pit number 16 (SD: 3.76, range: 12-22) were found. As body ray cell diameter was narrower and length was longer, it conducted safranine solution in higher depth than that of marginal ray cell. Because body ray cell faced little obstacle for liquid conduction compared with marginal ray cell. On the other hand, very thin lumen diameter and absence of endwall made intercellular space more permeable than ray cells. Following the same methodology, safranine solution penetration depth was explained in radial

direction of *Populus tomentiglandulosa* T. Lee by Ahmed et al. (2007). If we compare the anatomical features between two species, it will explain the reason behind for high permeability of safranine solution in *P. sargentii*. Because of narrow lumen diameter and presence of numerous pit in endwall of procumbent ray cell, made this species more permeable than that of *Populus tomentiglandulosa*.

Table 2. Safranine solution flow depth in longitudinal direction unit: μm

Time (second)	Vessel		Wood fiber	
	Sapwood	Heartwood	Sapwood	Heartwood
3.8	635.40b	426.84NS	237.91b	208.10NS
7.5	732.69ab	459.95 NS	282.34b	250.50NS
11.3	783.1ab	500.68 NS	448.85a	267.21NS
15.0	888.44a	549.04 NS	475.34a	297.59NS

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

In longitudinal direction, vessels are reported as the main avenue for liquid conduction (Stamm and Raleigh 1967). Vessels are connected end to end through perforation plate and made a tube like structure. The resulting vessel can be long and continuous, as for example upto three meters in length have been reported (Thomas 1981). In this report we found that vessel was more permeable than wood fiber and sapwood was more permeable than heartwood. Sapwood was 1.61 times more permeable than heartwood and vessel was 1.86 times more permeable than wood fiber. But if we consider about the capillary pressure theory then this result does not support it. The reason was for the structure of vessel. Vessels can make a tube by interconnecting end to end through simple perforation plate. In fiber this kind of structure is totally absent. Through simple to minutely bordered pits present in fiber help to diffuse liquid from one cell to neighboring with a lot of obstacle. Furthermore, it is thought that air trapped in fiber lumen reduce or stop the liquid flow. In vessel, the trapped air can bypass through numerous intervessel pits or through perforation plates which made vessel more permeable rather than fiber.

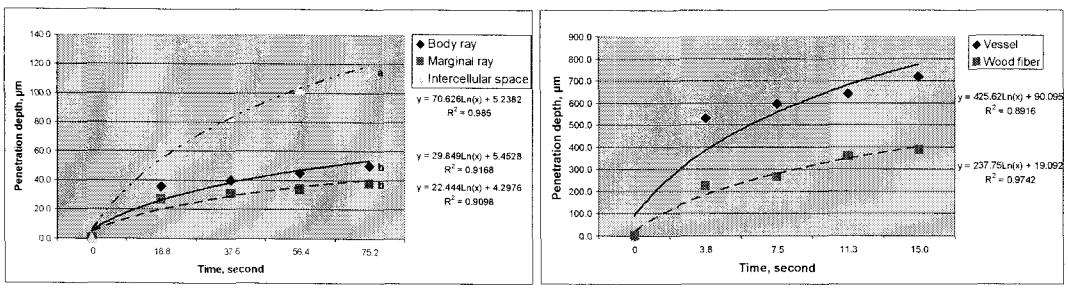

Fig.2. Comparison of safranine solution flow in radial direction (left) and in longitudinal direction (right).

In this experiment we found the vessel length 412.11μm (SD: 110.40, range: 216.33-580.90μm), vessel diameter 45.23μm (SD: 7.16, range: 29.33-59.75μm), fiber length 762.77μm (SD: 206.97, range: 414.30-1118.53μm) and fiber diameter 6.35μm (SD: 1.74, range: 3.28-9.91μm). Following same methodology, longitudinal penetration of safranine solution was observed in *Populus tomentiglandulosa* at 23.27% wood moisture level reported by Choi et al. (2007). Longer vessel and wood fiber were the reasons for the higher safranine solution conduction depth in *Populus*

tomentiglandulosa. It is also reported that excess moisture in wood void can reduce the permeability (Wirspa and Libby 1950). In *P. sargentii,* the average moisture content was recorded as 26.5% which was higher than wood moisture in *Populus tomentiglandulosa* used in above mentioned experiment.

In radial direction, safranine solution penetration flow rate was found high at 18.8 second of penetration and gradually decreased about 81% at 37.6 second, 85% at 56.4 second and 90% at 75.2 second. In longitudinal direction, flow rate decreased about 87% at 7.5 second, 86% at 11.3 second and 91% at 15.0 second. So, liquid flow depth can be increased if we prolong the treatment time.

CONCLUSIONS

Safranine solution penetration depth was found high in sapwood compared to heartwood. In radial direction, intercellular space conducted safranine in higher depth. Body ray parenchyma was found more permeable than square marginal ray cells. Different anatomical features like, ray cell length, lumen diameter, endwall pit number were found responsible for the variation of liquid penetration depth. In longitudinal direction, penetration depth of liquid mainly affected by wood moisture content, vessel length, vessel diameter, wood fiber length and diameter. Further more vessels were found to be the main avenue for deep penetration of safranine solution. Initial flow rate was high and gradually the flow rate decreased. More research work is suggested using different solutions to observe the liquid effects on the penetrability.

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