Assessment of the Differences between Juvenile and Mature Woods of *Populus alba* Trees in the Longitudinal and Radial Axes of the Stem

Ali Hassanpoor Tichi

The aim of this study was to evaluate the differences between juvenile and mature woods of *Populus alba* trees in the axial and radial directions of the stem. For this purpose, three stands of *P. alba* trees were randomly chosen and cut from at their diameter at breast height. Three disks with a thickness of 5 cm were taken at three different height levels along the tree stems. The specimens were sequentially cut in the radial position according to the ISO standards method. The results indicated that there are significant differences in the physical and biometric features of *P. alba* trees in the longitudinal and radial axes of the stem. As the height from the base of the tree to the top of the stem increased, the oven-dry density, basic density, and fiber biometric factors decreased. Moreover, as the distance from the pith to the bark increased, the oven-dry density, basic density, and fiber biometric factors increased. The microscopic study represented that the *P. alba* is a semi-ring-porous hardwood with distinct growth ring boundaries, simple perforation, homogenous rays, and alternative inter-vessel pits.

DOI: 10.15376/biores.17.1.1385-1396

Keywords: Semi-ring-porous; Populus alba; density; Biometric; Anatomical

*Contact information: Department of Wood Industry, Technical and Vocational University (TVU), Tehran, Iran; *Corresponding author: hasanpoortichi@gmail.com*

INTRODUCTION

Trees are one of the most important renewable resources to any country. Tree's features such as renewability, environmental friendliness, affordability, strength, low production energy, and aesthetics (natural beauty) separate them from other non-renewable materials such as metal, cement, and polymers. Due to the high production energy consumption, environmental damage, and high price of these non-renewable materials, the global demand for wood-based products is increasing. Therefore, the importance of proper usage and awareness of wood characteristics are vital. Engineered wood products, such as glued laminated timber, are extensively used for construction instead of materials such as metal and cement. However, it should be considered that the end use of wood correlates closely with fundamental features (biometric, anatomical, and physical properties) of the species that is used. Since wood is a biological substance, its fundamental features are varied at different parts of the stem. Therefore, extensive research has been done on this subject, but the fundamental features variations of the *Populus alba* specie are rarely examined.

Silver poplar, silverleaf poplar, or white poplar is a hardwood tree that is placed in the Malpighiales order, Salicaceae family, and *Populus* genus with a scientific name of *P. alba*. This species is native to Europe and Asia and distinguishable from other poplars by its 3 to 5 lobed silvery leaves. *P. alba* is a fast-growing deciduous and medium-sized tree that reach 30 to 40 m in height and 1 m in diameter by maturity, and it is often seen growing as a multi-trunked tree. The bark on young *P. alba* trees is smooth and greenish-gray, but it matures to a dark gray-black color with ridges and furrows. White poplars are dioecious, with tiny reddish male and greenish female flowers that appear in separate catkins on separate male and female trees in the spring (April) before the foliage emerges. Wood formed during the first three or so years of life of a tree is generally dominated by the so-called juvenile wood, and then mature wood is produced. Juvenile wood often has different properties than mature wood. In general, juvenile wood is considered inferior to mature wood in terms of mechanical and physical properties. It is weaker, less stiff, more prone to warp, and is more problematic to process into paper and fiber products. Differences in the cell structure and chemistry of juvenile wood are again responsible for macroscopic features. There are select circumstances or situations in which juvenile wood is considered acceptable, and perhaps even, preferable. Low-density wood-based composites and some paper products would be examples of products in which juvenile wood performs acceptably and with consistency. Cell length, cell wall thickness, and percentage of latewood per ring are lower in juvenile wood. This combination of structural features results in lower density. The S2 microfibril angle is increased (more horizontal) over mature wood, as is the percent of lignin in the cell walls. Parsapajouh and Schweingruber (2001) evaluated the anatomical features of *P. alba*. Their study showed that *P. alba* is a diffuse-porous hardwood with distinct growth ring boundaries, solitary pores, or radial multiples of two, three, or four vessels that are abundant with the same size and regularly distributed across the growth rings. The parenchyma cell is diffuse and present at the terminal of the growth rings. Rays are uniseriate and between 5 and 20 cells in height. Vessels have simple perforations and intervessel pits are abundant and large. Vessel-ray pits are arranged in three to four horizontal rows and the rays are homogenous. Cobas *et al*. (2013) investigated the juvenile to mature wood transition in one clone of *Populus deltoides* implanted in Buenos Aires, Argentina. They concluded that the estimated age of transition from juvenile wood and mature wood was not identical for all properties. The transition ages were 4, 5, 7, and 9 years, depending on the variable such as means of the parameters: density, morphometry of fibers, and vessels in one poplar clone.

The sequence of maturation was: cell wall area, vessel diameter and frequency, fiber width and length, density, and wall thickness.

The anatomical and physical properties of juvenile and mature wood of *P. alba* and *P. euramericana* was studied by Efhami and Saraeyan (2008). The results of their research indicated that the basic density of *P. alba* at breast height diameter and near the pith zone was 0.311 g/cm^3, and it regularly increased toward the bark. The biometric factors of *P. alba*, such as the fiber length, fiber diameter, fiber lumen diameter, and fiber wall diameter were 1120 µm, 26.8 µm, 18.4 µm, 4.26 µm in mature wood and 825.45 µm, 23.37 µm, 16.89, and 3.27 µm in juvenile wood, respectively.

The variation of within-stem biometrical and physical property indices of wood from *Cupressus sempervirens* L. was examined by Hashemi and Kord (2011). Their study concluded that the tracheid length, tracheid cross-sectional dimension, oven-dry density, and basic density decreased from the base upward and increased from the pith to the bark.

Ramazani *et al.* (2012) investigated the anatomical, biometric, and chemical characteristics of juvenile and mature wood of *P. alba*. They concluded that the biometric factors of fiber increased from the pith to the bark. The fiber length, fiber diameter, fiber lumen diameter, and fiber wall diameter were 600 µm, 18.8 µm, 12.8 µm, and 2.9 µm in juvenile wood and 843.03 µm, 22.6 µm, 14.2 µm, and 4.2 µm in mature wood, respectively. The results also revealed that *P. alba* is a semi ring-porous hardwood with solitary pores and vessels in radial multiples of two, three, or four that are commonly seen. Solitary vessels with large pores are mostly presented in early and juvenile wood, and vessel perforation is simple. Rays are homogenous and uniseriate and inter-vessel pits are alternative.

Tichi *et al.* (2020) evaluated the anatomical, biometric, and physical properties of *Citrus sinensis* trees. They concluded that the physical and biometric factors including the basic density, oven-dry density, fiber length, fiber diameter, fiber lumen diameter, and fiber wall thickness increased from the pith to the bark and decreased from the base upward.

The density, microscopic, and biometric features of *Parrotia persica* trees were studied by Tichi *et al.* (2021). They showed that all the biometric and density features including the basic density, oven-dry density, fiber length, fiber diameter, fiber lumen diameter, and fiber wall thickness significantly increased from the pith to the bark and decreased from the base to the top of the tress.

Therefore, the main purpose of this research was to determine the anatomical, physical, and morphological features of *P. alba* trees in different parts of the stem, as well as its impact on the functional properties of this species.

EXPERIMENTAL

Materials

To conduct experiments on the *P. alba* species, three completely healthy *P. alba* trees in Neka, Mazandaran, Iran at a geographical coordinate of 53° 20’ E and 36° 40' N were randomly selected and felled with a height of 5 m and a diameter of 60 cm (at breast height). The stems did not have any defects including cracks, biological defects, mechanical damages, checks, or splits. The age of the trees was 35. From each stem, three 5 cm thick discs were taken at three height levels (1.30 m, 3 m, and 4.5 m) along the trees stems. Next, within each disc, the specimens with dimension of 3 cm (length) × 2 cm (width) × 2 cm (height) were sequentially taken from the pith to the bark (Fig. 1). To conduct the physical and anatomical experiments, the specimens were transported to the wood and paper industries laboratory (room conditions of 20°C temperature and 65% relative humidity) of Shahid Hasheminejad Technical University in Sari, Iran.

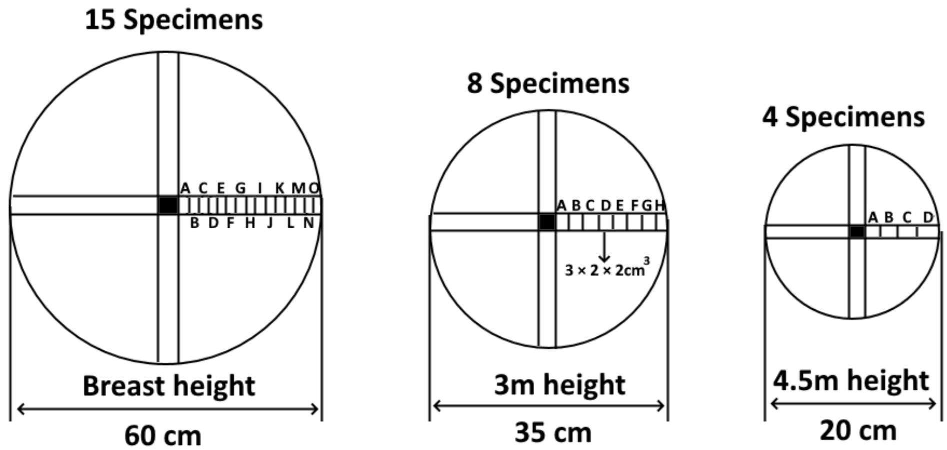


Fig. 1. The cutting pattern and number of test samples at three height levels

Methods

Determining of physical features

To determine the basic density and oven-dry density of the *P. alba* trees, the ISO 13061-2 standard (2014) was used. To evaluate the changes in the basic density and oven-dry density of the *P. alba* in the longitudinal and radial axes of the stem, the 3 cm × 2 cm × 2 cm test specimens were obtained with a cross-sampling technique from each disc from the pith to the bark. The orthotropic and geometrical axes in specimens were completely matched together. Then, wooden blocks were immersed in water for a week to completely saturate in water. The green bulk of blocks were measured using a digital caliper (EK610i; AND, Tokyo, Japan) with an accuracy of 0.01 mm, and the test specimens were put in oven at a temperature of 103 ± 2 °C until the specimens completely dry after 24 h. Next, the dry weight of the samples was obtained with a digital scale with an accuracy of 0.001 g. The dry bulk of samples were measured when no changes were observed in the dry weight of the samples. The oven-dry density and the basic density were calculated according to Eq. 1 and Eq. 2,

$$D_o = \frac{M_0}{V_0} \quad (1)$$

$$D_b = \frac{M_0}{V_S} \quad (2)$$

where D_O is the oven-dry density (g/cm^3), D_b is the basic density (g/cm^3), M_0 is the dry mass (g), V_0 is the dry volume (cm^3), and V_S is the saturated volume (cm^3).

Measuring the biometric factors of the fibers

The measuring of the fiber biometric factors, including the fiber length, fiber diameter, fiber lumen diameter, and fiber wall thickness was performed using Franklin's method (1945). To determine the change trends of the biometric factors for the *P. alba* trees, 3 cm × 2 cm × 2 cm test samples were obtained from each disk. The samples were sequentially obtained from the pith to the bark. Matchsticks of fiber were obtained from each block with 3 cm × 2 mm × 2 mm dimensions and put in the tube with a mixture of acetic acid (CH_3COOH) and hydrogen peroxide (H_2O_2) at a 1:1 ratio. The tubes were labeled and kept in the oven at a temperature of 70 °C for 24 h. Next, the bleached fibers were washed with distilled water for five to six times and shaken in the test tube to macerate the fibers and stained them with safranin. The fibers were then transferred from the test tube to a microscopic slide. The biometric factors of at least 30 straight fibers were measured using a light microscope (CX22; Olympus, Tokyo, Japan). The fiber length was measured by 10× magnification from an objective lens. The fiber diameter, fiber lumen diameter, and fiber wall thickness were measured by 100× magnification of objective lens.

Preparation of the microscopic section

The microscopic structure near the *P. alba* bark wood was examined in accordance with the IAWA list of hardwoods (Wheeler *et al.* 1989). A block from near the bark area (3 cm × 2 cm × 2 cm) was taken from a disk at breast height. Next, the specimen was immersed in a glycerol and distilled water solution with a 1:1 ratio for 48 h to soften the tissue and promote better sectioning. Then, microscopic sections that were approximately 15 µm thick were taken from the block using a microtome (ROTO-CUT 100 Advance; Scilab, Bransley, England) that was equipped with a knife angle of approximately 15° for hardwood tissue. Next, microscopic sections were immersed in javel water (sodium hypochlorite) for 15 to 30 min to the extract the cellular content. The microscopic sections were then rinsed with distilled water two to three times to remove the odor of the javel water. The sections were painted with dual safranin (0.04%) and astra-blue (0.15%) solution two to three times. The microscopic sections were rinsed with distilled water and 50% alcohol once, 96% alcohol two to three times until the excess paint was removed, and 100% alcohol once. Next, the micro sections were immersed in xylol to remove the alcohol. Finally, each micro section was mounted on microscopic slide with a 50 g of pressure on the coverslip and put in the oven at 50 °C for 24 h. The micro-sections were analyzed using a light microscope equipped with a graduated eyepiece (Parsapajouh and Schweingruber 2001).

Statistical analysis

The statistical analyses were performed using Statistica version 13 software (TIBCO Software, Palo Alto, CA, USA) at a significance level of α=0.05. The obtained results were analyzed statistically, and an analysis of variance (ANOVA) test was performed to determine the significance of the tested parameter. A Duncan's multiple range test (DMRT) was performed to compare the treatment means.

RESULTS AND DISCUSSION

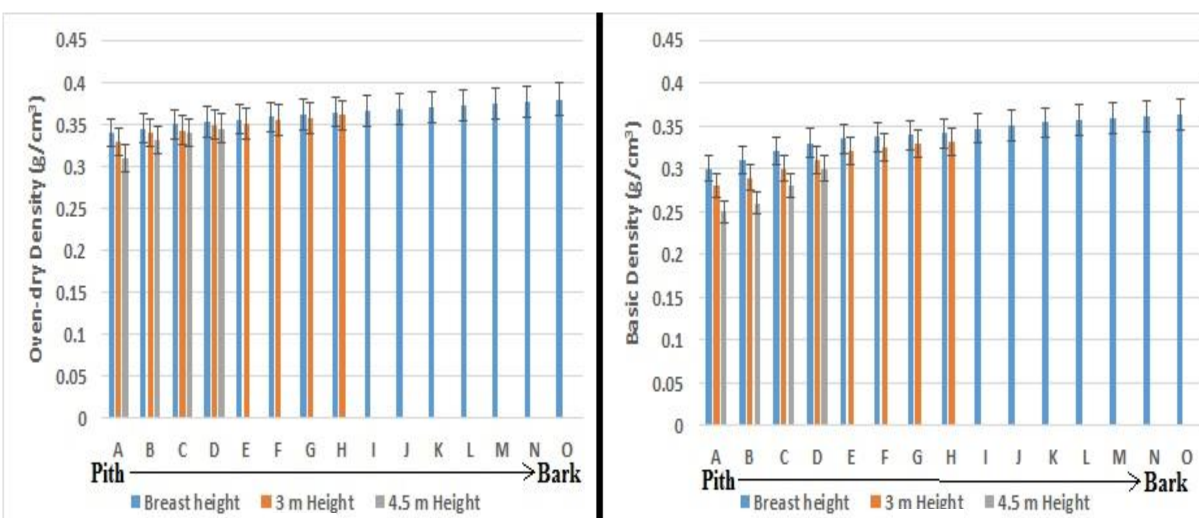
Physical Features

The results from the examination of the oven-dry density and the basic density of the *P. alba* showed that the independent and interaction effects of the longitudinal and radial axes of the tree stem were significant relative to the oven-dry density and the basic density at a confidence level of 95%. As the height along the tree stem from the base toward the top increased, the oven-dry density and the basic density values decreased. As the distance from the pith to the bark increased at three height levels of 1.5 m, 3 m, and 4.5 m, the oven-dry density and basic density values increased. The highest oven-dry density and basic density values were 0.38 g/cm^3 and 0.36 g/cm^3 at breast height level near the bark wood (block O), respectively. The lowest oven-dry density and basic density values were

0.31 g/cm^3 and 0.25 g/cm^3 at 4.5 m height level near the pith wood (block A), respectively (Fig. 2).

The average changes in the oven-dry density and the basic density of the *P. alba* trees in the radial position from the pith to the bark regularly increased. These results aligned with the research by Hashemi and Kord (2011) and Tichi *et al.* (2021). A living tree in the early years of its life produces a wood that is called juvenile wood. Depending on the species, after a few years the tree starts to produce a wood that is called mature wood. Juvenile and mature woods have some vital differences in the fiber length, the fiber lumen diameter, the fiber wall thickness, the density, the longitudinal shrinkage, and the microfibril angle (Tichi *et al.* 2020). The main reason for these differences in the cell structure is the initial cambium activity in the tree. Regarding the larger mature wood volume near the bark area compared to the pith area and the larger fiber wall thickness near the bark area, it is concluded that the density increased from the pith to the bark. However, the oven-dry density and the basic density decreased as the height from the pith to the bark increased, which can be explained by the higher proportion of juvenile wood at the higher zone of the tree (Tichi *et al.* 2021).

Density is one of the most important features of wood, and it is vital in many wood applications. The density of wood species correlates with the mechanical properties of particleboard, parallel strand lumber, laminated strand lumber, and oriented strand lumber. In the production of these boards, there is a very important ratio known as the compression ratio. This ratio decreases as the wood density increases. As the compression ratio decreases, the bond and compression between wood particles, chips, and strands decreases, which reduces the mechanical strength of these boards. Moreover, in wood construction, the knowledge of wood densities is vital because the density of finished wood products correlates with the wood density. The *P. alba* species has a low density, which is suitable to mix with high-density species to produce boards with appropriate compression ratios. Furthermore, the wood density correlates with wood quality that can predict timber strength, stiffness, ease of drying, machining, and hardness. The wood density is also related to fiber properties, pulp yield, and various papermaking applications. Therefore, the awareness of wood density and its impact on the different parts of the tree is very important.



A B

Fig. 2. The changes in the A) oven-dry density and the B) basic density of *P. alba* trees from the pith (block A) to the bark (block O) zone at three height levels

Biometric Features

The independent and interaction effects of the longitudinal and radial axes of the stem on the fiber length, fiber diameter, fiber lumen diameter, and fiber wall thickness were significant at a 95% confidence level. As the height along the tree stem increased, all the biometric factors decreased. However, as the distance from the pith to the bark increased, all the biometric factors increased at each of the three height levels. The highest fiber length, fiber diameter, fiber lumen diameter, and fiber wall thickness values were 0.89 mm, 20 µm, 16.11 µm, and 3.89 µm at the breast height level near the bark area (block O), respectively. The lowest fiber length, fiber diameter, fiber lumen diameter, and fiber wall thickness values were 0.47 mm, 14.87 µm, 12.47 µm, and 2.4 µm at the crown area near the pith wood (block A), respectively (Fig. 3). Due to the fact that the fiber length of this tree is short, it is therefore not very suitable for the pulp and paper industry.

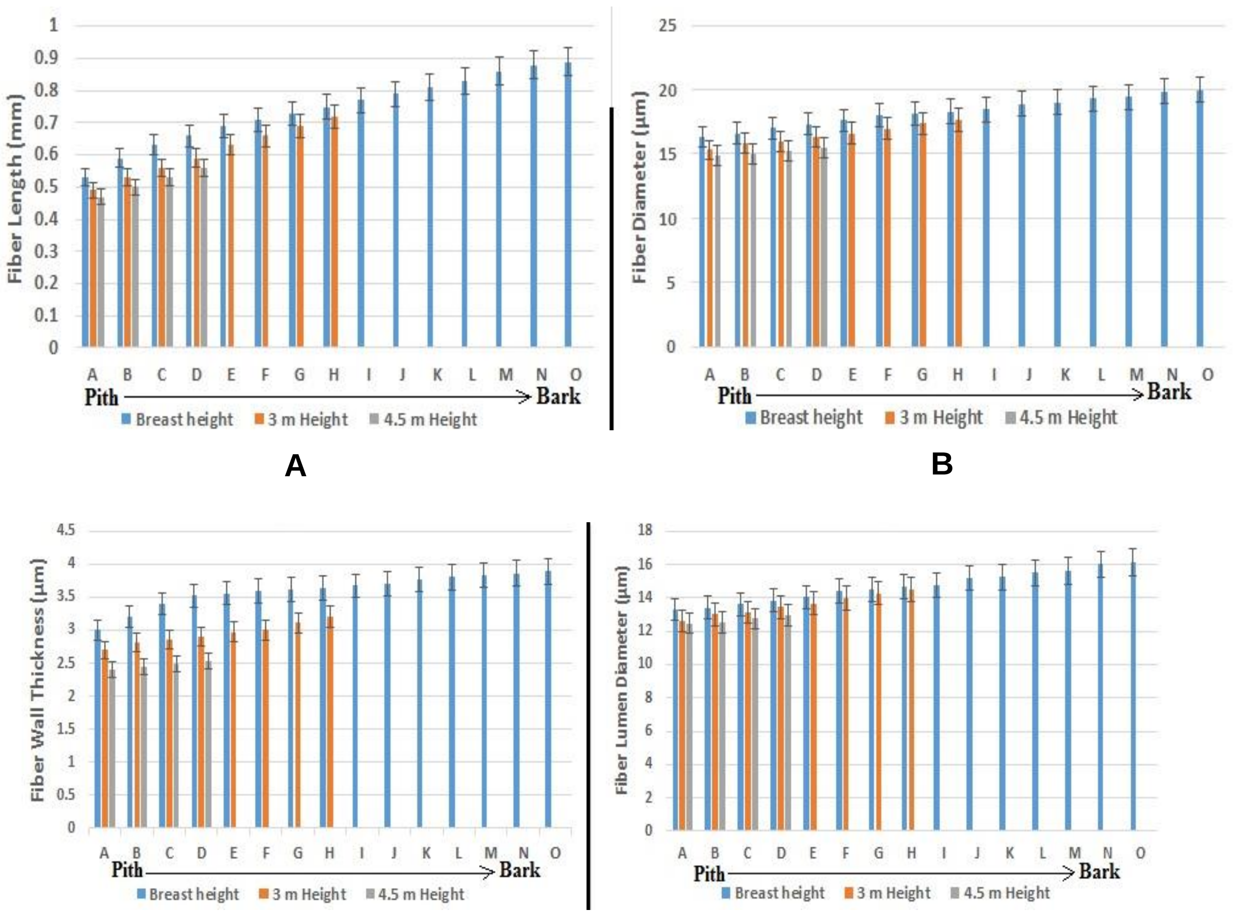


Fig. 3. The changes in the A) fiber length, B) fiber diameter, C) fiber wall thickness, and D) fiber lumen diameter of *P. alba* trees from near the pith (block A) to near the bark (block O) zone at three height levels

Regarding the results from the biometric analyses of the *P. alba* trees, as the age of the trees and the distance from the pith and the reach to the bark increased, the average value of all the biometric factors including the fiber length, fiber diameter, fiber lumen diameter, and fiber wall thickness increased. The changes in these biometric factors were attributed to the activity of the initial cambium cells in the juvenile and mature wood zone, which has a linear relationship with the fiber length (Zobel and van Buijtenen 1989; Zobel and Sprague 1998; Tichi *et al.* 2021). Cells that are produced in the early years of a tree's life do not have a mature cellular structure because the initial cambium cells are not able to produce cells with a mature structure. However, as the age of the tree increases due to the evolution of the initial cambium cells, the produced cells have a more mature structure. This aligns with the results obtained from the physical exam, where it was found that the increased density from the pith to the bark was attributed to the increased fiber wall thickness. Furthermore, the main reason for the reduction in the fiber biometric factors when the height along the tree was increased can be attributed to the presence of a higher volume of juvenile wood at the top zone of the tree (Adamopoulos and Voulgaridis 2002; Marsoem *et al.* 2002). These results are consistent with the research conducted by Tichi *et al.* (2021) and Zobel and Sprague (1998). According to the IAWA list of hardwoods, the fiber is divided into three categories in terms of length. These include short fibers with a length of less than 900 µm, medium fibers with a length of 900 to 1,600 µm, and long fibers with a length of more than 1,600 µm (Wheeler *et al.* 1989). *P. alba* fibers are categorized as short fibers. Fiber length has an undeniable correlation with paper features. For instance, the fiber length is related to the rankle ratio, slenderness ratio, and flexibility ratio. The biometric factors of fibers are variable at different parts of the tree, so knowledge of the trends of these features is vital for pulp and paper mills.

Anatomical Features

To accurately examine the anatomical features of the *P. alba* specimens, the microscopic structure near the bark wood of the *P. alba* tree was studied according to the IAWA list of hardwoods (Table. 1).

Table 1. Microscopic Features near the Bark Zone of *P. alba* According to the IAWA List of Hardwoods

Feature	Number of Features	Description (Mature Wood)
Growth Rings	1	Growth ring boundaries distinct
Porosity	4	Wood semi-ring-porous
Vessel Arrangement	6	Vessel in tangential bands
	7	Vessel in diagonal pattern
	7	Vessel in diagonal pattern
Vessel Groupings	9	Vessel exclusively solitary
	10	Vessel in radial multiples of 2,3, or 4
Perforation Plates	13	Simple perforation plates
Intervessel pits: Arrangement and Size	22	Intervessel pits alternate
	23	Shape of alternate pits polygonal
	25	Small (4 to 7 µm)
Vessel-ray Pitting	31	Vessel-ray pits with much reduced borders to apparently simple
Mean Tangential Diameter of Vessel Lumina	40	≤ 50µm
Vessel per mm^2	50	≥ 100
Mean Vessel Element Length	52	≤ 350 µm
Tyloses and Deposits in the Vessels	-	-
Ground Tissue Fibers	61	Fiber with simple to minutely bordered pits

Septate fibers and parenchyma-like fiber bands	66	Non-septate fiber present
Fiber wall thickness	69	Fibers thin to thick walled
Mean fiber length	71	≤ 900 µm
Axial parenchyma	75	Axial parenchyma absent or extremely rare
Ray width	96	Rays exclusively uniseriate
Ray height	102	Ray height > 1 mm (Maximum: 17 cells height)
Rays: cellular composition	104	All ray cells procumbent
Rays per mm	115	4 to 12 rays per mm
Prismatic crystals	-	-

The results showed that *P. alba* is a semi-ring-porous species with distinct growth ring boundaries, simple perforation, alternative intervessel pits, and vessel-ray pits with much reduced borders. Vessel grouping was mainly in the radial multiples of two or three, but solitary pores and tangential multiples of two were observed.

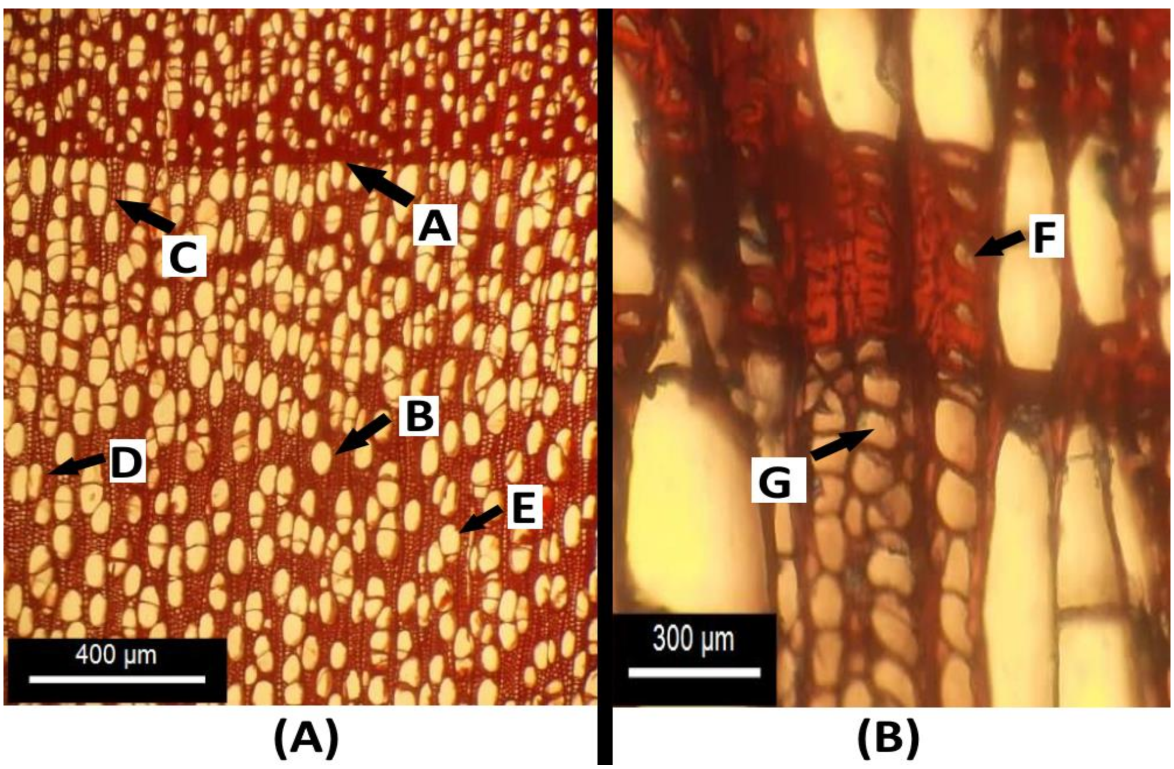


Fig. 4. The cross section of the *P. alba* tree at the A) 400 µm scale and B) 300 µm scale. The distinct growth ring boundary (arrow A), solitary pore (arrow B), vessels in radial multiples of two (arrow C), vessels in tangential band (arrow D), vessels in diagonal pattern (arrow E), late wood fiber (arrow F), and early wood fiber (arrow G) are illustrated

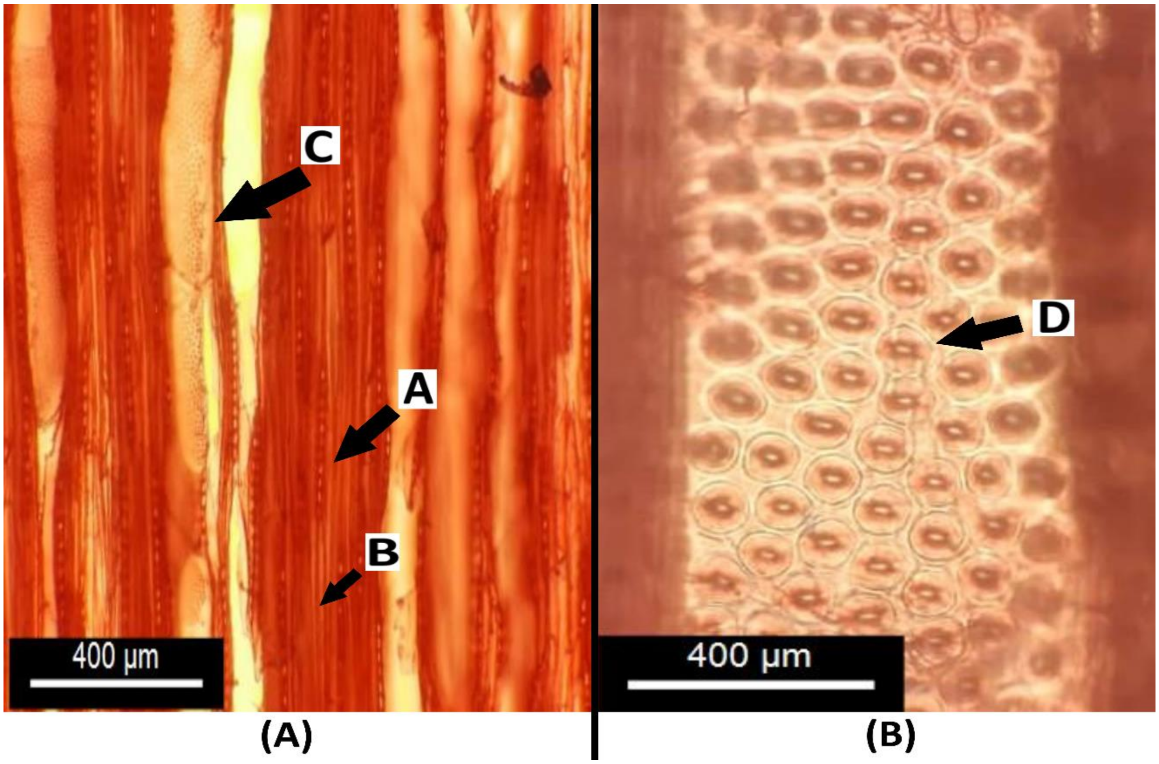


Fig. 5. The tangential section of the *P. alba* tree at the 400 µm scale. The uniseriate ray (arrow A), fiber cell (arrow B), vessel line (arrow C), and alternative inter-vessel pits (arrow D) are illustrated.

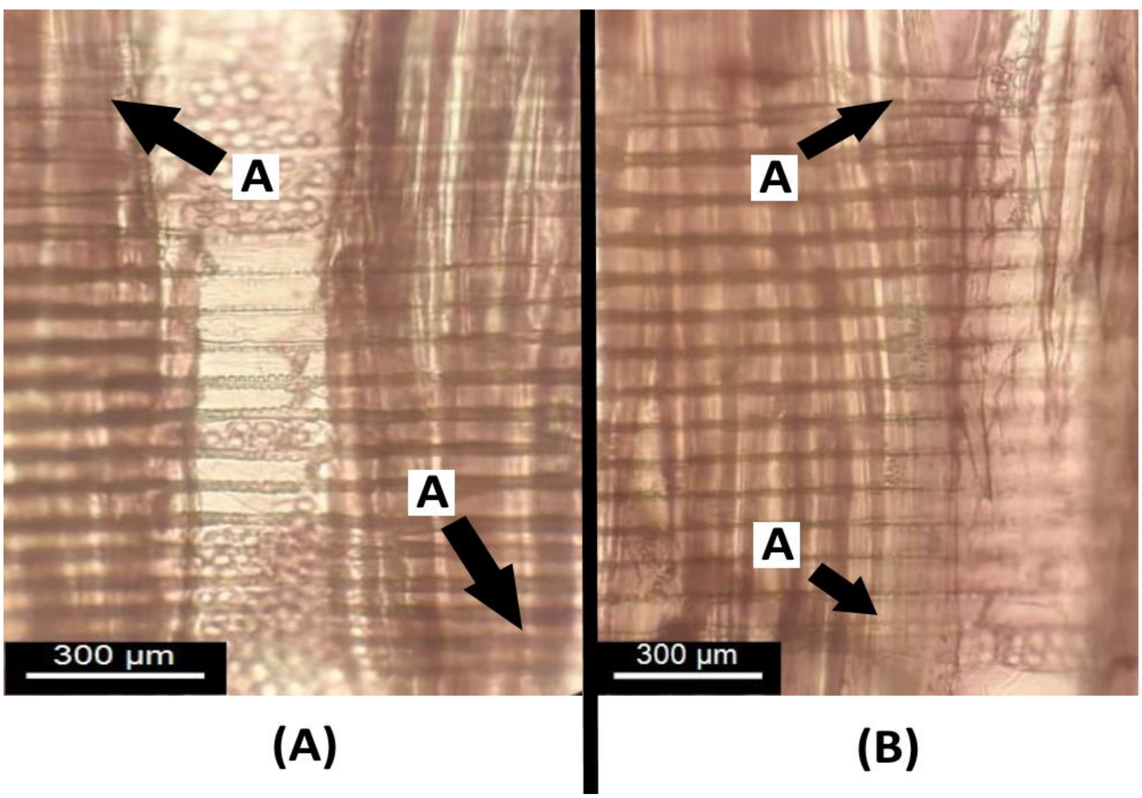


Fig. 6. The radial section of the *P. alba* tree at the 300 µm scale. The homogenous ray cells are all procumbent (arrow A).

The vessel arrangement was mainly in the radial pattern, but tangential bands and diagonal patterns were observed. Furthermore, the mean tangential diameter of the vessels was 37 µm and there were 210 vessels per mm. In the tangential section, the rays were uniseriate at 5 to 17 cells in height. In the radial section, the rays were homogeneous with procumbent ray cells (Figs. 4, 5, and 6).

CONCLUSIONS

1. All the biometric factors of *Populus alba* trees, including the fiber length, fiber diameter, fiber lumen diameter, and fiber wall thickness significantly decreased from base upward and increased from the pith to the bark.
2. The oven-dry density and basic density of *P. alba* decreased upward from the base to the top, and the densities increased with increasing distance from the pith to the bark.
3. Microscopy showed that *P. alba* is semi-ring-porous with distinct growth ring boundaries, simple perforation, homogenous rays, and alternative inter-vessel pits.

ACKNOWLEDGMENTS

The authors appreciate the constant scientific support of Mojtaba Rezanezhad Divkolae (Department of Wood and Paper Sciences, Faculty of Natural Resources, Tarbiat Modares University).

REFERENCES CITED

Adamopoulos, S., and Voulgaridis, E. (2002). "Within-tree variation in growth rate and cell dimensions in the wood of black locust (*Robinia pseudoacacia*)," *IAWA Journal* 23(2), 191-199. DOI: 10.1163/22941932-90000297

Cobas, A., Area, M., and Monteoliva, S. (2013). "The juvenile to mature wood transition in one clone of *Populus deltoides* implanted in Buenos Aires, Argentine," *Maderas Cienc. Tecnol.* 15(2), 223-234. DOI 10.4067/S0718221X2013005000018

Efhami, D., and Saraeyan, A. R. (2008). "Evaluation of anatomical and physical properties of juvenile/mature wood of *Populus alba* and *Populus* × *euramericana*," *Iranian Journal of Wood and Paper Science Research* 24(1), 134-147. DOI: 10.22092/IJWPR.2009.117363

Franklin, G. L. (1945). "Preparation of thin sections of synthetic resins and wood-resin composites, and a new macerating method for wood," *Nature* 155, 51. DOI: 10.1038/155051a0

Hashemi, S. K. H., and Kord, B. (2011). "Variation of within-stem biometrical and physical property indices of wood from *Cupressus sempervirens L.*," *BioResources* 6(2), 1843-1857.

ISO 13061-2 (2014). "Physical and mechanical properties of wood − Test methods for small clear wood specimens – Part 2: Determination of density for physical and mechanical tests," Int. Organization for Standardization, Geneva, Switzerland.

Marsoem, S. N., Haryanti, E., and Lukmandaru, G. (2002). "Radial and axial variation in the fibre dimensions and cell proportion of auri (*Acacia auriculiformis*) wood grown in the community forest," in: *The Fifth Pacific Regional Wood Anatomy Conference*, Yogyakarta, Indonesia, pp. 9-14.

Parsapajouh, D., and Schweingruber, F. H. (2001). "Different stage of the procedure," in: *Atlas of the Woods of North of Iran*, Tehran University Publications, Tehran, Iran.

Ramazani, S., Talaeipour, M., Aliabadi, M., Tabeai, A., and Bazyar, B. (2012). "Investigation of the anatomical, biometry and chemical characteristics of juvenile and mature poplar (*Populus alba*) wood," *Iranian Journal of Wood and Paper Science Research* 28(1), 182-193. DOI: 10.22092/IJWPR.2013.3114

Tichi, A. H., Khademieslam, H., and Divkolae, M. R. (2020). "Evaluation of physical, anatomical, and biometric characteristics of *Citrus sinesis* trees in longitudinal and transvers axes of stem," *BioResources* 15(3), 5696-5709. DOI: 10.15376/biores.15.3.5696-5709

Tichi, H. A., Gholamiyan, H., and Divkolae, M. R. (2021). "Changes in biometric, density, and microscopic features of *Parrotia persica* trees in longitudinal and radial directions of the stem," *BioResources* 16(2), 3563-3574. DOI: 10.15376/biores.16.2.3563-3574

Wheeler, E. A., Baas, P., and Gasson, P. E. (1989). "IAWA list of microscopic features for hardwood identification," *IAWA Bulletin New Series* 10(3), 219-332.

Zobel, B. J., and Sprague, J. R. (1998). "Predictions of mature and total tree wood properties from juvenile wood," in: *Juvenile Wood in Forest Trees*, Springer-Verlag, Berlin, Germany, pp. 173-187.

Zobel, B. J., and van Buijtenen, J. P. (1989). "Variation within and among trees," in: *Wood Variation: Its Causes and Control*, Springer, Berlin, Germany, pp. 72-131.

Article submitted: October 21, 2021; Peer review completed: December 19, 2021; Revised version received and accepted: January 2, 2022; Published: January 10, 2022.
DOI: 10.15376/biores.17.1.1385-1396