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Evaluation of the Basic Properties for the Korean Major Domestic Wood Species I. Korean Red Pine (*Pinus densiflora*) in Pyeongchang-gun, Gangwon-do

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ABSTRACT

Wood has different properties depending on the species or growth area. Therefore, in order to use wood efficiently, it is necessary to have a proper understanding of the characteristics of wood depending on the species and the appropriate use for them. In particular, in order to effectively use more than 1,000 species of woody plants in South Korea as wood, it is necessary to evaluate the characteristics of various Korean domestic woods and make a database of them. In this study, the anatomical properties (length and width of tracheid, cell wall thickness), physical properties (specific gravity and shrinkage), mechanical properties (bending strength, compressive strength, tensile strength, shear strength, hardness), and chemical composition (ash, extract, lignin, total sugar content) of Korean red pine which was grown in Pyeongchang-gun, Gangwon-do, South Korea were evaluated.

Keywords: Korean red pine, anatomical property, physical property, mechanical property, chemical composition

1. INTRODUCTION

Wood is a sustainable and unlimited resource produced by nature through photosynthesis, thus differentiated from other industrially produced materials such as metals and plastic. Another benefit is that, at the end of use and disposal, wood is returned to nature through microbial degradation, which makes it an environmentally-friendly material. On the other hand, wood is a material composed of a variety of cells to exhibit such unique characteristics as heterogeneity and anisotropy so that care should be taken in processing and use of wood materials. Notably, each species show different wood properties and even for an identical species, wood pro-

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perties may vary according to growth area or tree age, and hence, to use a wood material efficiently, it is necessary to properly understand the characteristics of a given wood species and its respective usage.

South Korea has a wide spectrum of climatic regions from warm-temperate forests to temperate forests, with high proportion occupied with forest areas as well as complex topography that leads to various vegetative conditions. As a result, vegetative structures are relatively complex for the territorial area, with a diversity of tree species. In the Korean Plant Names Index (KPNI), the forests in South Korea contain 1,234 species of woody plants, among which native species account for the largest number at 1,074 species, in addition to 7 species of naturalized plants and 203 species of introduced plants for use in afforestation and tests (KNA, 2011). For valuable use of such diverse woody plants, a database of wood properties of each species should be developed.

Korean red pine (*Pinus densiflora*) is an evergreen coniferous tree species representative of South Korea as it grows nationwide in areas ≤ 1,000 m altitude. The average tree height and diameter are 35 m and 1.8 m, respectively. *P. densiflora* has long been used in a variety of fields; construction, civil engineering, furniture, packaging, bridge and pulp. Additionally, its leaves and pollen powder are used in food and medicine (KNA, 2011). As *P. densiflora* has been used for various purposes, it has also been widely applied as a test specimen in research on changes in quality properties according to different processes and the characteristics of the material (Choi *et al*., 2020, 2022; Gong *et al*., 2021; Han *et al*., 2022; Jang, 2022c; Jung and Yang, 2018; Jung *et al*., 2019, 2021, 2022; Kim and Kim, 2018, 2021; Kim *et al*., 2017, 2018, 2020; Lee and Bae, 2021; Lee and Kim, 2022; Lee *et al*., 2021c, 2022a, 2022b, 2022c; Min *et al*., 2019).

To develop a database of wood properties of Korean major species, this study analyzed and report the anatomical properties (tracheid length and width, cell wall thickness), physical properties (specific gravity, shrinkage), mechanical properties (bending strength, compression strength, tensile strength, shear strength, hardness) and chemical composition (ash, extractives, lignins, sugar content) of *P. densiflora*.

2. MATERIALS and METHODS

2.1. Materials

In this study, 40 straight-grain Korean red pine logs with ≥ 300 mm diameter at the upper end were selected and used (Fig. 1). The average age was approximately 42 years, and the production site for the logs was San 80-1, Jinjo-ri, Bongpyeong-myeon, Pyeongchang-gun, Gangwon-do, South Korea (N37.56°, E128.31°).

2.2. Evaluation of basic wood properties

For the basic wood properties of the *P. densiflora*, anatomical properties (tracheid length and width, cell

Fig. 1. Production site for *Pinus densiflora*.

wall thickness), physical properties (specific gravity, shrinkage), mechanical properties (bending strength, compression strength, tensile strength, shear strength, hardness) and chemical composition (ash, extractives, lignins, sugar content) were analyzed. The wood specimen used in the experiment was extracted from the heartwood excluding juvenilewood and manufactured so that the annual rings at the cross section were parallel to the edges, considering the heterogeneity and anisotropy of wood (Fig. 2). Most property evaluations were conducted according to the KS or ASTM specifications. For the anatomical properties with no standard specifications, methods in previous studies were adopted (Table 1).

2.2.1. Anatomical properties

2.2.1.1. Tracheid length

From the mature wood of *P. densiflora* (≥ 20 rings), cubic specimens (10 mm length on each side) were obtained, then long and thin match shapes were cut in the fiber direction using a knife. The resulting specimens were immersed in a solution of 1:1 (w/w) mixture of 30% H_2O_2 and 95% CH_3COOH, and using a heating mantle, the mixture was heated at 80℃ for 48 h to dissociate the fibers (Franklin method). The dissociated fibers were stained using methylene blue, and 1.25 × images were obtained using an optical microscope (Axio imager A1, Carl Zeiss, Jena, Germany). The tracheid length was measured using an image analysis program, and the mean of 30 measurements was estimated.

2.2.1.2. Tracheid width and cell wall thickness

From the mature wood of *P. densiflora* (≥ 20 rings), cubic specimens (10 mm length on each side) were obtained, and the mixture was placed in a solution of 1:3 (w/w) mixture of glycerin and distilled water for softening through 1 h boiling. Using a sliding microtome, cross-sections of 10 μm thickness were prepared, and 20 × images were obtained using an optical microscope. Next, the tracheid width and cell wall thickness in radial and tangential directions were measured. The mean of 30 measurements was estimated.

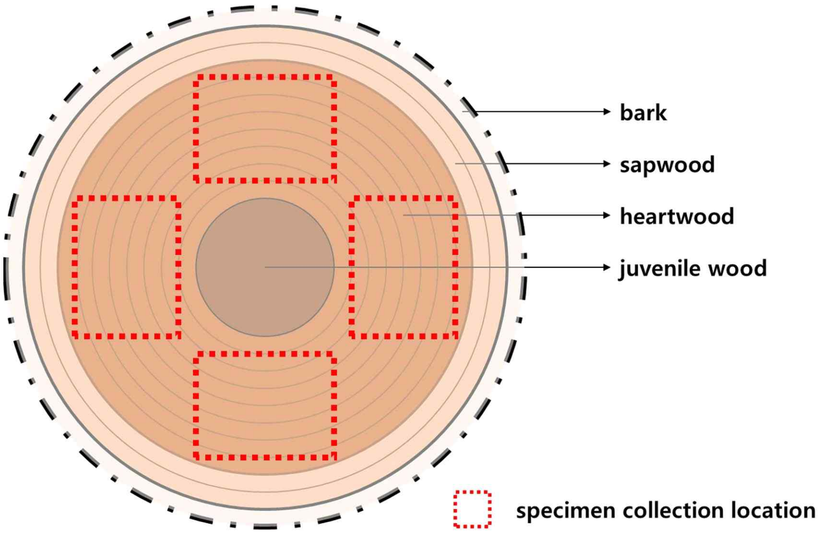


Fig. 2. Location of specimens collected from log.

Table 1. Standard and reference for the evaluation of wood properties

Property		Standard	Reference
Anatomical properties	Length of cell	-	Jang, 2022a, 2022b, 2022d, 2022e; Jeon *et al*., 2018a, 2018b, 2020; Kim *et al*., 2018; Laksono *et al*., 2023; Lee and Bae, 2021, Lee *et al*., 2021a, 2021b, 2021c; Marbun *et al*., 2019; Nam and Kim, 2021; Park *et al*., 2018, 2022, 2023; Purusatama *et al*., 2018; Savero *et al*., 2020
	Width of cell	-	
	Thickness of cell wall	-	
Physical properties	Specific gravity	KS F 2198	Ahn *et al*., 2021; Darwis *et al*., 2023; Hadi *et al*., 2019, 2022; Iswanto *et al*., 2017; Kang *et al*., 2023; Kim and Kim, 2018, 2019; Maulana *et al*., 2017; Nawawi *et al*., 2023; Özcan and Korkmaz, 2019; Pari *et al*., 2023; Park *et al*., 2015a, 2015b, 2016, 2018; Priadi *et al*., 2021; Savero *et al*., 2020; Schulz *et al*., 2021; Seta *et al*., 2023; Trisatya *et al*., 2023
	Shrinkage	KS F 2203	
Mechanical properties	Bending strength	KS F 2208	Cha *et al*., 2022; Darwis *et al*., 2023; Fujimoto *et al*., 2021; Hadi *et al*., 2019, 2022; Hwang and Oh, 2021; Hwang *et al*., 2021; Iswanto *et al*., 2017; Kang *et al*., 2023; Kim *et al*., 2020; Lee and Jang, 2023; Lee and Oh, 2023; Liu *et al*., 2022; Maulana *et al*., 2017; Oh, 2021, 2022; Özcan and Korkmaz, 2019; Park *et al*., 2015b, 2016; Qi *et al*., 2019; Savero *et al*., 2020; Schulz *et al*., 2021; Song and Kim, 2023; Sumardi *et al*., 2022; Trisatya *et al*., 2023
	Compression strength	KS F 2206	
	Tensile strength	KS F 2207	
	Shear strength	KS F 2209	
	Hardness	KS F 2212	
Chemical composition	Ash	KS M ISO 18122	Adfa *et al*., 2023; Cahyani *et al*., 2023; He *et al*., 2021; Huh *et al*., 2022; Iswanto *et al*., 2021; Jain *et al*., 2022; Jung *et al*., 2019, 2021, 2022; Manurung *et al*., 2019; Maulana *et al*., 2021; Maulina *et al*., 2020; Min *et al*., 2019; Purnawati *et al*., 2018; Seo *et al*., 2020
	Extractives	ASTM E 1690	
	Lignin	ASTM E 1758-01	
	Sugars		

2.2.2. Physical properties

2.2.2.1. Specific gravity and shrinkage

To measure the specific gravity and shrinkage, *Determination of density and specific gravity of wood* (KS F 2198; Korean Standards Association, 2016) and *Test method for shrinkage of wood* (KS F 2203; Korean Standards Association, 2020a) were followed. After preparing 100 cubic specimens (20 mm on each side), the lengths in longitudinal, radial and tangential directions and weight for green, air-dry, and oven-dry states were measured to evaluate the specific gravity and shrinkage in green, air-dry, and oven-dry states.

2.2.3. Mechanical properties

The mechanical properties were measured for air-dry and green states (the hardness was measured only for air-dry state). The specimens for the green state were immersed in distilled water until constant dimensions were reached, prior to the experiment. The specimens for the air-dry state were humidified in a constant temperature (20℃) and relative humidity (65%) chamber until constant weights were reached, prior to the experiment. The results obtained for air-dry state were adjusted based on 12% moisture content for subsequent analysis.

2.2.3.1. Bending strength

To measure the bending strength, *Method of bending test for wood* (KS F 2208; Korean Standards Association, 2020d) was used. After preparing 40 rectangular specimens of 300 mm (longitudinal direction) × 20 mm (radial direction) × 20 mm (tangential direction) in dimension, 20 specimens each were used in the experiments for air-dry and green states. A 3-point test was performed to assess bending at 280 mm span and 5.5 mm/min load speed.

2.2.3.2. Compression strength

To measure the compression strength, *Method of compression test for wood* (KS F 2206; Korean Standards Association, 2020b) was used. After preparing 30 rectangular specimens of 60 mm (longitudinal direction) × 20 mm (radial direction) × 20 mm (tangential direction) in dimension, 15 specimens each were used in the tests for air-dry and green states. The load speed was set at 0.4 mm/min.

2.2.3.3. Tensile strength

To measure the tensile strength, *Method of tension test for wood* (KS F 2207; Korean Standards Association, 2020c) was used. After preparing 30 rectangular specimens of 200 mm (longitudinal direction) × 10 mm (radial direction) × 30 mm (tangential direction) in dimension, 15 specimens each were used in the tests for air-dry and green states. As shown in Fig. 3, all specimens were prepared with the center in a concave shape to focus the tension. The load speed was set at 5.0 mm/min.

2.2.3.4. Shear strength

To measure the shear strength, *Method of shear test for wood* (KS F 2209; Korean Standards Association, 2020e) was used. After preparing 80 rectangular specimens of 60 mm (longitudinal direction) × 50 mm (radial direction) × 50 mm (tangential direction) in dimension, 20 specimens each were used in the experiments on the sections (radial and tangential) and moisture content (green and air-dry). As shown in Fig. 4, the corners were removed in each specimen so that the dimension of the shear plane was 50 mm (longitudinal direction) × 50 mm (radial or tangential direction). The load speed was set at 0.8 mm/min.

2.2.3.5. Hardness

To measure the hardness, *Test method for static hardness of wood* (KS F 2212; Korean Standards Association, 2020f) was used. After preparing 60 cubic specimens (50 mm on each side), 20 specimens each were used in the tests for cross, radial and tangential sections. An iron ball of 5.64 mm radius was placed at the center of the each section for hardness measurement

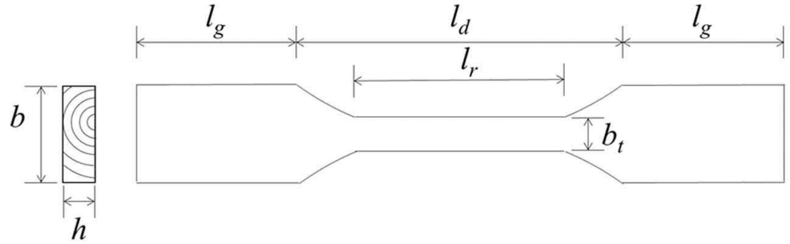
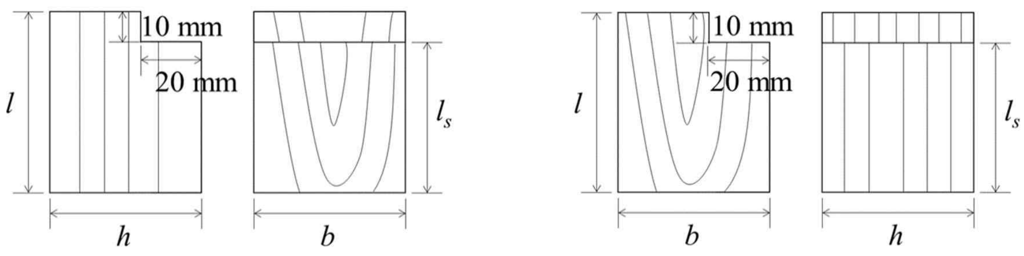


Fig. 3. Tensile specimen in longitudinal direction.



(a) (b)

Fig. 4. Shear specimen. (a) Tangential section, (b) radial section.

with indentation at 3.0 mm/min of load speed.

2.2.4. Chemical composition

2.2.4.1. Ash

To measure the ash content, *Solid - Determination of ash content* (KS M ISO 18122; Korean Standards Association, 2015) was used. The samples were pulverized to ≤ 1 mm and dried in a 60℃ dryer for at least one day. In an aluminum plate, 1 g of dried wood powder was placed for the first incineration in a 250℃ furnace (heating rate: 4.5℃/min) for 1 h, followed by the second incineration in a 550℃ furnace (heating rate: 10℃/min) for 2 h. The content of ash remaining on the plate was measured, and the mean of triplicate measurements was presented as the ash content.

2.2.4.2. Extractives

To measure the contents of extractives, *Standard Test Method for Determination of Ethanol Extractives in Biomass* (ASTM E 1690; ASTM, 2021) was used. The samples were pulverized to ≤ 1 mm and dried in a 60℃ dryer for at least one day. The extraction applied a solution of 1:2 (v/v) mixture of alcohol and benzene, to which 2 g of dried wood powder was added. After 6 h extraction, the contents of extractives were measured, and the mean of triplicate measurements was presented as the extractive content.

2.2.4.3. Lignins

To measure the contents of lignins, *Standard Test Method for Determination of Carbohydrates in Biomass by High Performance Liquid Chromatograph* (ASTM E 1758-01; ASTM, 2020) was used. After removing the extractives, 0.3 g of wood powder was added to a solution of 72% H_2SO_4 for the 2 h first reaction in a constant-temperature water bath set at 30℃. At the completion of reaction, the H_2SO_4 solution was diluted to 4% for the 1 h second reaction in an autoclave set at 121℃. The residual content undissolved in the H_2SO_4 solution was determined as the amount of acid-insoluble lignins. The dissolved content was determined as the amount of acid-soluble lignins via UV absorption analysis. The total lignin content was the sum of acid-insoluble and acid-soluble lignin contents. The mean of triplicate measurements was presented as the lignin content.

2.2.4.4. Sugar content

To measure the sugar content, *Standard Test Method for Determination of Carbohydrates in Biomass by High Performance Liquid Chromatograph* (ASTM E 1758-01; ASTM, 2020) was used. High performance liquid chromatography was performed on 1 mL of the liquid sample after the second reaction in the H_2SO_4 solution in *2.2.4.3 Lignins*, to determine the sugar content. The column was Aminex HPX-87H (300 × 7.8 mm, Bio-Lad Laboratories, Hercules, CA, USA) and a refractive index detector was used. The conditions were column temperature at 40℃ and 0.01N H_2SO_4 mobile phase at 0.6 mL/min flow rate. The mean of triplicate measurements was presented as the total sugar content.

3. RESULTS and DISCUSSION

3.1. Anatomical properties

Analyzing the anatomical properties of *P. densiflora*, the tracheid length was 2.00 mm for earlywood and 2.31 mm for latewood, and the tracheid width was 39.23 μm in radial direction and 34.57 μm in tangential direction for earlywood and 12.75 μm in radial direction and 20.94 μm in tangential direction for latewood. The cell wall thickness was 3.74 μm for earlywood and 5.22 μm for latewood.

3.2. Physical properties

Analyzing the specific gravity and shrinkage of *P. densiflora*, the specific gravity was 0.370, 0.385, and 0.408 in green, air-dry, and oven-dry states, respectively, and the total shrinkage in each direction was 0.78% in longitudinal direction, 2.35% in radial direction, and 6.54% in tangential direction, while the total volumetric shrinkage was 9.44%.

3.3. Mechanical properties

Analyzing the mechanical properties of *P. densiflora*, the bending strength was 67.8 MPa in air-dry state and 38.1 MPa in green state; the compression strength was 30.9 MPa in air-dry state and 15.1 MPa in green state; the tensile strength was 68.0 MPa in air-dry state and 57.1 MPa in green state; the shear strength in radial section was 6.9 MPa in air-dry state and 3.6 MPa in green-state; the shear strength in tangential section was 8.0 MPa in air-dry state and 4.4 MPa in green state. Lastly, the hardness in air-dry state was 3.9 kN in cross section, 2.2 kN in radial section, and 2.6 kN in tangential section.

3.4. Chemical composition

Analyzing the chemical composition of *P. densiflora*, the ash content was 0.19%, while the content of extractives was 6.91%. For the content of lignins, there were 26.04% acid-insoluble lignins and 1.84% acid-soluble lignins; hence, 27.88% total lignins. The total sugar content was 63.99% with 44.42% glucan, 18.97% XMG, and 0.60% arabinan.

4. CONCLUSIONS

In this study, the anatomical, physical, and mechanical properties as well as chemical composition of *P. densiflora* (in Pyeongchang-gun, Gangwon-do, South Korea) as a representative evergreen coniferous tree in South Korea were evaluate to build a database for the wood properties of Korean major species (Table 2). Wood exhibits varying its properties depending on the growth area so that the wood properties of *P. densiflora* grown in a single area as in this study cannot be generalized to all Korean red pine wood in South Korea. Therefore, to determine a representative value for wood property of Korean red pine, it is necessary to comparatively analyze the wood properties of *P. densiflora* grown in different areas, for which the results of this study could serve as basic data. Further studies will be conducted to provide additional data on the basic properties of various wood species and growth areas to build a database for wood properties of Korean major wood species in each area.

CONFLICT of INTEREST

No potential conflict of interest relevant to this article was reported.

Table 2. Basic properties of Korean red pine

Anatomical properties

Length of tracheid		Width of tracheid				Thickness of cell wall	
		Earlywood		Latewood			
Earlywood	Latewood	R section	T section	R section	T section	Earlywood	Latewood
2.00 mm	2.31 mm	39.23 µm	34.57 µm	12.75 µm	20.94 µm	3.74 µm	5.22 µm
(0.17)	(0.16)	(5.48)	(3.04)	(1.98)	(1.63)	(0.57)	(0.69)

Physical properties

Specific gravity			Total shrinkage			
			Linear			
Green	Air-dry	Oven-dry	L direction	R direction	T direction	Volumetric
0.370	0.385	0.408	0.78%	2.35%	6.54%	9.44%
(0.043)	(0.043)	(0.044)	(0.68)	(0.82)	(1.48)	(1.88)

Mechanical properties

Bending strength		Compression strength parallel to the grain		Tensile strength parallel to the grain	
Air-dry (12% MC)	Green	Air-dry (12% MC)	Green	Air-dry (12% MC)	Green
67.8 MPa	38.1 MPa	30.9 MPa	15.1 MPa	68.0 MPa	57.1 MPa
(5.0)	(4.7)	(1.9)	(1.7)	(12.4)	(11.7)

Shear strength				Hardness		
R section		T section		C section	R section	T section
Air-dry (13.8% MC)	Green	Air-dry (13.8% MC)	Green	Air-dry (12% MC)	Air-dry (12% MC)	Air-dry (12% MC)
6.9 MPa	3.6 MPa	8.0 MPa	4.4 MPa	3.9 kN	2.2 kN	2.6 kN
(0.5)	(0.4)	(1.1)	(0.5)	(0.3)	(0.4)	(0.5)

Chemical compositions

Ash	Extractives	Lignin		
		Acid-insoluble	Acid-soluble	Total
0.19%	6.91%	26.04%	1.84%	27.88%
(0.02)	(0.09)	(0.23)	(0.18)	(0.40)

Sugars			
Glucan	XMG	Arabinan	Total
44.42%	18.97%	0.60%	63.99%
(0.55)	(0.55)	(0.13)	(1.04)

SD in parentheses.
L direction: Longitudinal direction, R direction: Radial direction, T direction: Tangential direction, C section: Cross section, R section: Radial section, T section: Tangential section.
MC: moisture content, XMG: xylan + mannan + galactan.

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