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Evaluation of the Basic Properties for the Korean Major Domestic Wood Species II. Tulip Tree (*Liriodendron tulipifera*) in Gangjin-gun, Jeollanam-do

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ABSTRACT

Wood has different cell composition and characteristics depending on the wood species, and even though they are the same species, their characteristics can differ depending on the growing area. Therefore, in order to use wood effectively, it is very important to accurately know the characteristics of wood according to the wood species and the appropriate use for it. Tulip trees have been widely planted throughout South Korea since the early 2000s because they grow quickly, have excellent environmental adaptability, and have excellent carbon absorption capabilities. In this study, the anatomical properties (length and width of the trachea, 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 Tulip tree which was grown in Gangjin-gun, Jeollanam-do, South Korea were evaluated. The evaluation results show that the Tulip tree, a fast-growing species, has low specific gravity, relatively low strength, and a chemical composition similar to general hardwoods.

Keywords: Tulip tree, anatomical property, physical property, mechanical property, chemical composition

1. INTRODUCTION

Although wood is an environmentally friendly material that is naturally produced through photosynthesis, it is also composed of a variety of cells that have unique properties, such as non-uniformity and anisotropy, which necessitate careful processing and utilization (Chong and Park, 2008). Given the variability in wood properties across species and even within the same species, depending on the growing region and age, it is essential to understand the characteristics of wood and its appropriate use to ensure efficient utilization of wood (Park *et al*., 2024). In a recent study, Park *et al.* (2024) evaluated the anatomical properties (length, width, and cell

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wall thickness for the tracheid), 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 (*Pinus densiflora*) grown in Pyeongchang, Gangwon-do, Korea, with the objective of establishing a comprehensive database of wood properties for major tree species in Korea. This study aims to present the results of evaluating the fundamental material properties of the Tulip tree (*Liriodendron tulipifera*) cultivated in Gangjin, Jeollanam-do.

The Tulip tree is a deciduous broad-leaved tree that was introduced from North America in the 1920s and subsequently planted throughout Korea. It typically reaches an average height of 30 m with a diameter of 0.5 to 1.0 m. The Tulip tree is capable of withstanding frost and is not adversely affected by air pollution. It is relatively free from pests and has a long lifespan (Kim *et al.*, 2007). In particular, it has been extensively cultivated throughout the Korea since the early 2000s due to its rapid growth, environmental adaptability, and high carbon absorption capacity (Lim *et al.*, 2022). Representative successful forests include Chodang Forest in Gangjin-gun, Jeollanam-do, Soyang Forest in Wanju-gun, Jeollabuk-do, and Gumi National Forest in Gyeongsangbuk-do, and are known to thrive relatively well in western Gyeonggi-do, Chungcheongnam-do, Jeollanam-do, and Jeollabuk-do.

The Tulip tree has a history of utilization in a variety of applications, including furniture, packaging, interior decoration, veneer, and plywood. However, recent years have seen a shift in focus towards exploring its potential for a broader range of uses. In particular, given the rapid growth rate and plentiful resources of the Tulip tree, research has been actively pursued to identify optimal pretreatment conditions and assess its potential for biofuel production (Gwak *et al.*, 2024; Kim *et al.*, 2009, 2011, 2015, Shin *et al.*, 2009). In recent studies, the specific gravity, strength, porosity, adhesion, and carbonization properties of Tulip tree have been evaluated to assess its potential as a building material (Jang *et al.*, 2019; Kim *et al.*, 2023; Lee and Eom, 2011; Lim *et al.*, 2010; Song and Kim, 2022). Additionally, studies have been conducted to assess the characteristics of heat-treated Tulip trees as a means of addressing the inherent durability issues associated with Tulip trees (Chang *et al.*, 2019; Kim *et al.*, 2010; Yoon *et al.*, 2009).

2. MATERIALS and METHODS

2.1. Target species

The study selected and used 40 Tulip tree logs with a diameter of 300 mm or more from Mountain 49-1 (N34.55°, E126.87°), Myeongju-ri, Chilyang-myeon, Gangjin-gun, Jeollanam-do, Korea (Fig. 1). The mean age of the logs used in this experiment was approximately 28 years.

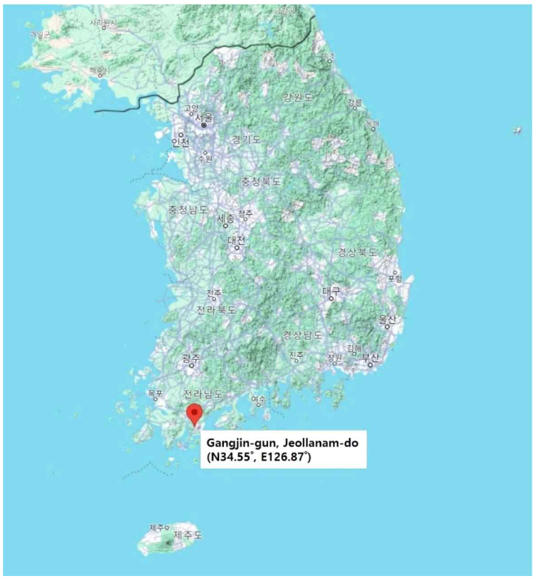

Fig. 1. Tulip tree production site.

2.2. Evaluation of base material properties

The anatomical properties (length, width, and cell wall thickness for the vessel element and wood fiber), 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 the Tulip tree were analyzed. The evaluation of each wood property was performed in the same way as in previous studies (Park *et al*., 2024). In most cases, KS or ASTM standards were followed, as shown in Table 1, but for anatomical properties without standardized specifications, the experimental methods were determined by referring to previous studies (Kim *et al*., 2024; Lee and Bae, 2021; Lee *et al*., 2021a, 2021b, 2021c; Nam and Kim; 2021). The specimens used in this experiment were sawn from heartwood devoid of immature wood, as illustrated in Fig. 2, exhibiting annual rings parallel to the edges to account for the inherent heterogeneity and anisotropy of wood.

3. RESULTS and DISCUSSION

3.1. Anatomical properties

As for the anatomical properties of the Tulip tree, the length of the wood fibers was 1.33 mm in early wood and 1.74 mm in late wood; the width of the early wood fibers was 21.19 μm radially and 22.67 μm tangentially; and the width of the late wood fibers was 12.82 μm radially and 11.14 μm tangentially. The cell wall thickness of wood fiber was measured to be 3.24 μm in early wood and 5.40 μm in late wood.

The length of the vessel element was measured to be 0.75 mm in early wood and 0.71 mm in late wood, and

Table 1. Standard for the evaluation of wood properties

Property		Standard
Anatomical properties	Length of cell	-
	Width of cell	-
	Thickness of cell wall	-
Physical properties	Specific gravity	KS F 2198 (Korean Standards Association, 2016)
	Shrinkage	KS F 2203 (Korean Standards Association, 2020a)
Mechanical properties	Bending strength	KS F 2208 (Korean Standards Association, 2020d)
	Compression strength	KS F 2206 (Korean Standards Association, 2020b)
	Tensile strength	KS F 2207 (Korean Standards Association, 2020c)
	Shear strength	KS F 2209 (Korean Standards Association, 2020e)
	Hardness	KS F 2212 (Korean Standards Association, 2020f)
Chemical composition	Ash	KS M ISO 18122 (Korean Standards Association, 2015)
	Extractives	ASTM E 1690 (ASTM, 2021)
	Lignin	ASTM E 1758-01 (ASTM, 2020)
	Sugars	

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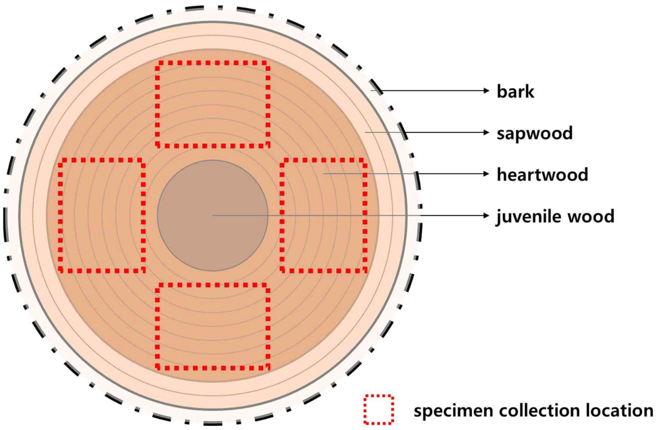


Fig. 2. Location of specimens collected from log. Adapted from Park *et al*. (2024) with CC-BY-NC.

the width of the early wood vessel element was measured to be 83.44 μm radially and 60.32 μm tangentially, while the width of the late wood vessel element was measured to be 59.73 μm radially and 47.29 μm tangentially. The cell wall thickness of the vessel element was measured to be 1.48 μm in early wood and 2.01 μm in late wood.

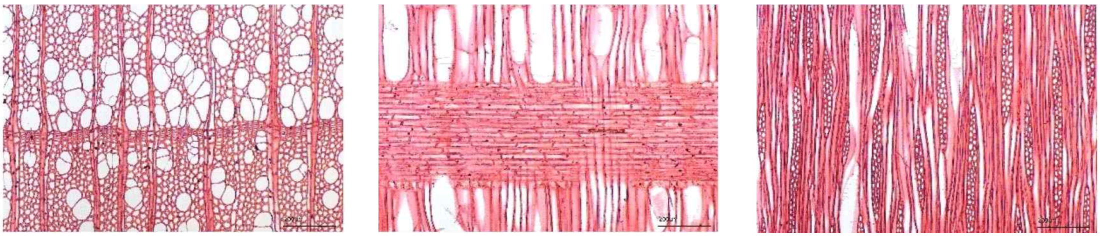
Fig. 3 shows an optical microscope image of three cross-sections of a Tulip tree to identify its cellular structure.

3.2. Physical properties

The specific gravity and shrinkage of the Tulip tree were measured, and the specific gravity was 0.406 for green wood, 0.437 for air-dried wood, and 0.461 for oven-wood. The shrinkage from green to oven-dried wood by direction was measured to be 0.39% in the fiber direction, 4.39% in the radial direction, and 7.30% in the tangential direction, with a volume shrinkage from green to oven-dried wood of 11.70%.

3.3. Mechanical properties

As a result of measuring the mechanical properties of the Tulip tree, the bending strength was measured to be 93.0 MPa in air-dried wood and 52.6 MPa in green wood; the longitudinal compressive strength was measured to be 39.0 MPa in air-dried wood and 18.5 MPa in green wood; and the longitudinal tensile strength was



(a) (b) (c)

Fig. 3. Optical microscope images for each section (1% Safranine solution). (a) Cross section (×10), (b) radial section (×10), (c) tangential section (×10).

Table 2. Basic properties of Tulip tree

Anatomical properties

Length of fiber (n = 30)		Width of fiber (n = 30)				Thickness of cell wall for fiber (n = 30)	
		Earlywood		Latewood			
Earlywood	Latewood	R section	T section	R section	T section	Earlywood	Latewood
1.33 mm (0.11)	1.74 mm (0.08)	21.19 μm (3.95)	22.67 μm (2.93)	12.82 μm (3.35)	11.14 μm (2.13)	3.24 μm (0.65)	5.40 μm (1.14)

Length of vessel element (n = 30)		Width of vessel element (n = 30)				Thickness of cell wall for vessel element (n = 30)	
		Earlywood		Latewood			
Earlywood	Latewood	R section	T section	R section	T section	Earlywood	Latewood
0.75 mm (0.10)	0.71 mm (0.08)	83.44 μm (6.11)	60.32 μm (7.64)	59.73 μm (8.54)	47.29 μm (6.84)	1.48 μm (0.29)	2.01 μm (0.27)

Physical properties

Specific gravity (n = 100)			Total shrinkage (n = 100)			
			Linear			
Green	Air-dry	Oven-dry	L direction	R direction	T direction	Volumetric
0.406 (0.041)	0.437 (0.048)	0.461 (0.054)	0.39% (0.25)	4.39% (1.32)	7.30% (2.03)	11.70% (3.02)

Mechanical properties

Bending strength		Compression strength parallel to the grain		Tensile strength parallel to the grain	
Air-dry (12% MC*) (n = 18)	Green (n = 18)	Air-dry (12% MC) (n = 18)	Green (n = 22)	Air-dry (11.3% MC) (n = 18)	Green (n = 15)
93.0 MPa (11.5)	52.6 MPa (7.9)	39.0 MPa (3.0)	18.5 MPa (2.4)	133.1 MPa (34.0)	83.3 MPa (11.5)

Shear strength				Hardness		
R section		T section		C section	R section	T section
Air-dry (12% MC) (n = 17)	Green (n = 15)	Air-dry (12% MC) (n = 18)	Green (n = 15)	Air-dry (12% MC) (n = 10)	Air-dry (12% MC) (n = 10)	Air-dry (12% MC) (n = 10)
7.4 MPa (0.9)	4.8 MPa (0.7)	7.7 MPa (1.1)	5.6 MPa (0.7)	4.6 kN (0.6)	2.8 kN (0.4)	3.4 kN (0.2)

Chemical compositions

Ash (n = 3)	Extractives (n = 3)	Lignin (n = 3)		
		Acid-insoluble	Acid-soluble	Total
0.27% (0.02)	2.49% (0.24)	22.04% (0.21)	2.40% (0.45)	24.44% (0.26)

Sugars (n = 3)			
Glucan	XMG**	Arabinan	Total
44.94% (1.59)	16.69% (0.71)	0.64% (0.11)	62.27% (1.69)

SD in parentheses.
n: number of specimens used in the evaluation or number of repetitions of evaluation.
R section: radial section, T section: tangential section, L direction: longitudinal direction, R direction: radial direction, T direction: tangential direction, C section: cross section; * MC: moisture content, ** XMG: xylan + mannan + galactan.

measured to be 133.1 MPa in air-dried wood and 83.3 MPa in green wood. The radial cross-sectional shear strength was measured to be 7.4 MPa in air-dried wood and 4.8 MPa in green wood, while the tangential cross-sectional shear strength was measured to be 7.7 MPa in air-dried wood and 5.6 MPa in green wood. Finally, the hardness of air-dried wood was measured to be 4.6 kN in the transverse section, 2.8 kN in the radial section, and 3.4 kN in the tangential section.

3.4. Chemical composition

The chemical composition analysis of the Tulip tree showed that the ash content was 0.27% and the extract content was 2.49%. The lignin content was identified as 22.04% acid-insoluble and 2.40% acid-soluble, for a total of 24.44%. The total sugar content was identified as 94% glucan, 16.69% XMG, and 0.64% arabinan, for a total of 62.27%.

4. CONCLUSIONS

This study evaluated the anatomical, physical, and mechanical properties, as well as chemical composition, of the Tulip tree (Gangjin-gun, Jeollanam-do), a representative forest tree species in Korea, with the aim of establishing a database of wood properties of major domestic trees (Table 2). Given the variability in the wood properties across different regions of cultivation, it is implausible that the wood properties of Tulip trees from a single region could accurately represent those of domestic Tulip trees. It is thus imperative to undertake a comparative and evaluative analysis of the wood properties of Tulip trees cultivated in disparate production zones, with a view to deriving representative wood properties of domestic Tulip trees. The results of this study can be employed as a foundation for such an endeavor. It is intended that, in the future, further data on the basic wood properties of a range of tree species and regions will be made available in order to create a database of wood properties by region for the major domestic tree species.

CONFLICT of INTEREST

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

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