

Effect of Tree Age on the Properties of Himalayan Birch (*Betula alnoides* Buch.-H.ex D.Don) Wood

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The purpose of this study was to determine the effect of four different age groups on wood properties, *i.e.*, anatomical, physical, and mechanical, of Himalayan birch (*Betula alnoides* Buch.-H.ex D.Don). The correlation between the properties was also discussed. The results indicated age influences the anatomical, physical, and mechanical properties of Himalayan birch. Results were comparable with other plantation species. Moreover, mechanical properties were highly correlated with the fibre morphology in Himalayan birch. Results from this present study indicate that the 15-, 20-, and 25-year-old Himalayan birch are suitable to be used for parquet, furniture, and other products. Generally, plantation-grown Himalayan birch has the potential to be a raw material to fulfill the demand for the timber industry.

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INTRODUCTION

Forest plantations have long been established to ensure a steady supply of raw materials for the wood industry. Forest plantations have become more important sources of timber in some countries to relieve pressure from over-harvesting of natural forest stands because the demand for wood products keeps increasing yearly (West 2006; Alain and Chirstian 2010). *Betula* spp. from the Betulaceae family is one of the species chosen for forest plantation in Yunnan Province, China, for its timber and other uses. This species is found in the Northern Hemisphere, particularly in northern temperate climate areas such as China. *Betula* spp., also known as birch, has not only exceptional physical and mechanical properties (Luostarinen and Verkasalo 2000; Collins and Fink 2022), but it is also abundant on the Eurasian continent (Dobrowolska *et al.* 2020).

Birch wood has been used to make sawn timber, plywood, parquet, furniture, and other items. Birch is a medium density wood with the lightest juvenile wood near the core and the heaviest wood at or near the surface. According to Luostarinen and Verkasalo (2000), this species is durable in dry conditions but is not suitable for outdoor use due to its sensitivity to fungal, decay, and insect damage. However, the properties of wood from plantation species are different from the wood from natural forests, and this leads to limitations in the applications of plantation wood (Jakubowski *et al.* 2020).

Therefore, it is important to study the properties of wood from forest plantations to ensure the quality of the timber. The properties to study are wood anatomical, physical, and mechanical properties. These properties could be an indicator to the other important

properties, such as strength, drying, and machining, and also for the suitable product of the timber (Toong *et al.* 2014; Nordahlia *et al.* 2023).

The objective of this study was to determine the effect of four different age groups on wood properties of Himalayan birch. The anatomical and physical characteristics of Himalayan birch at various ages were determined. Mechanical properties including modulus of rupture (MOR), modulus of elasticity (MOE), and compression strength were also assessed. Moreover, correlation factors between the properties were also presented in this research. It is hoped that these basic properties of Himalayan birch will be useful to wood-based industries in terms of exploring suitable products from this plantation species.

EXPERIMENTAL

Materials

Himalayan birch (*Betula alnoides* Buch.-H.ex D.Don) of various ages, *i.e.*, 10-, 15-, 20-, and 25-years-old, were harvested from a forest plantation area in DeHong Prefecture (GPS coordinates: 24.398872060 N 97.931232590 E), Yunnan Province, China. Three trees were cut at 15 cm above the ground from each age group. The total number of trees cut in this study was 12. Two 5-cm-thick discs from each tree were used for anatomical and physical properties research, whilst 2 m billet pieces were used for evaluation of mechanical properties. The diameter at breast height (DBH), wood diameter (cm), and bark thickness (mm) of Himalayan birch at 4 different ages are shown in Table 1.

Table 1. Diameter at Breast Height, Wood Diameter, and Bark Thickness of *Himalayan Birch* at 4 Different Ages

Age	DBH (cm)	Wood Diameter (cm)	Bark Thickness (mm)
10	15.1	13.7	4
15	18.1	15.7	7
20	25.0	22.6	8
25	28.3	23.6	11

Sapwood percentage

The sapwood percentage of from each stem was determined by measuring the radius of the disc and heartwood portion. The sapwood percentage was calculated using the following Eq. 1,

$$\text{Sapwood percentage} = (R^2 - r^2) / R^2 \times 100 \quad (1)$$

where R is average disc radius (mm), and r is average of heartwood radius (mm).

Anatomical study

Microscope slides were prepared by taking a wooden block of 1.0 x 1.0 x 1.0 cm³ from each species studied and boiling it in distilled water until it was well soaked and sank (Schweingruber *et al.* 2006). Each block's transverse, tangential, and radial surfaces were cut into thin sections of 15 to 20 μm using a sledge microtome. The thin sections were then immersed in 1% aqueous of Safranin-O for several minutes before being dehydrated with increasing concentrations of alcohol: 70%, 80%, 90%, and 95% until excess stain was removed. The sections were cleared in clove oil before mounting in Canada balsam and drying for a few days in a 60 °C oven.

The samples for maceration were cut into small matchstick-sized pieces and then placed in a test tube containing of 30% hydrogen peroxide and glacial acetic acid (1:1 mixture) (Wheeler *et al.* 1989). The test tube was then heated in a 45 °C water bath until the sticks became silvery white. To remove the excess acid, the softened sticks were washed with distilled water. After cleaning the sticks, they were shaken in distilled water to break up the fibres from each other. Finally, one or two drops of Safranin-O were added into the test tubes to stain the fibres for easy observation.

Thirty measurement for each anatomical features were measured using a light microscope (model BX53F; Olympus, Tokyo, Japan) to make microscopic observations. The Runkel and slenderness ratio were calculated based on values derived from the fiber properties (Abara and Bekele 2022). The Runkel ratio (Eq. 2) and slenderness ratio (Eq. 3) ratio was calculated as shown below,

$$\text{Runkel ratio} = 2FWT/d \quad (2)$$

where FWT is fiber wall thickness and d is lumen width,

$$\text{Slenderness ratio} = L/D \quad (3)$$

where L is fiber length and D is fiber diameter.

Physical Properties

Moisture content

All specimens for moisture content with dimension of 20 mm x 20 mm x 30 mm were weighed before and after drying in an oven at 103 ± 2 °C until a constant weight was obtained. The specimens were conditioned in desiccators with silica gel and their oven dry weights were determined. The MC was calculated in percentage terms using Eq. 4,

$$MC (\%) = (W_i - W_o) / W_o \times 100 \quad (4)$$

where MC is moisture content (%), W_i is initial weight of samples (g), and W_o is oven dry weight (g).

Oven-dry density

For density determination, 120 specimens with dimensions of 20 mm x 20 mm in x 30 mm (in radial x tangential x longitudinal directions) were cut based on dimensions stipulated in the BS 373 (1957) standard. The samples' oven dry weight was determined after 48 h of drying in an oven at 103 ± 2 °C. The air dry volume was determined by measuring the samples to the nearest 0.01 mm in the radial (R), tangential (T), and longitudinal (L) directions with digital Vernier calipers. The oven dry density was calculated using oven dry weight and air-dry volume, as shown in Eq. 5,

$$\text{Oven- dry density (kg/m}^3\text{)} = W_o / V_g \quad (5)$$

where W_o is oven dry weight (kg) and V_g is air-dry volume (m³).

Volumetric shrinkage

The volumetric shrinkage test was carried out under air-dry to oven-dry conditions based on ISO 13061-14:2016 (E) with some modification of initial samples (air-dry) used. In this study, samples measuring 20 mm x 20 mm x 30 mm were used, where the tangential, radial, and longitudinal dimensions of each sample were marked. The measurements were done to the nearest 0.01 mm using digital Vernier calipers. The weight was taken before

the samples were dried in an oven at 103 ± 2 °C for 48 h. The volumetric shrinkage of 120 specimens was measured and calculated according to Eq. 6,

$$\beta_v (\%) = (V_i - V_o) / V_i \times 100 \quad (6)$$

where β_v is volumetric shrinkage (%) from the air-dry to oven dry conditions, D_i is the volume, in cubic millimeters, of the air-dry test piece, and D_o is the volume, in cubic millimeters, of the test piece at absolutely dry (oven-dry).

Mechanical Properties

Bending strength

For mechanical testing, 120 specimens were cut and tested in accordance with BS 373 (1957). The static bending test dimensions were 20 mm x 20 mm x 300 mm. During the test, samples were supported at both ends over a 280 mm span. At mid-span, a load was applied at a constant speed of 6.6 mm min⁻¹.

Compression parallel to grain

The specimens with dimensions of 20 mm (width) x 20 mm (thickness) x 60 mm (length) were used for the compression parallel to the grain. Each specimen was vertically positioned. The bottom end was placed on the flat surface of the strength tester's hemispherical bearing, while the top end was subjected to a constant applied load. Loading was controlled and applied at a constant cross-head movement rate of 0.6 mm min⁻¹.

Statistical Analysis

An analysis of variance (ANOVA) was used to determine whether or not the differences in means were significant. If the differences were significant, the Least Significant Difference (LSD) at ($p \leq 0.05$) test was used to determine which means were significantly different from one another. Pearson correlation analysis was used to examine the relationships between the fibre morphology and mechanical properties. The correlation used the guide established by Evans (1996), which suggests for the absolute value of r: 0.00 to 0.19 is very weak; 0.20 to 0.39 is weak; 0.40 to 0.59 is moderate; 0.60 to 0.79 is strong; and 0.80 to 1.0 is very strong.

RESULTS AND DISCUSSION

Table 2 depicts the sapwood and heartwood of Himalayan birch at various ages. The colour of the wood distinguishes the sapwood and heartwood of this species. The sapwood is white in colour and heartwood has a light reddish brown colour. The sapwood is the lighter coloured (yellowish white) wood found adjacent to the bark, whereas the heartwood is the darker coloured (pale reddish brown) wood found to the inside of the sapwood (Wiedenhoeft 2010; Nordahlia *et al.* 2014). According to Table 2, age 10 had the highest percentage of sapwood value, and the value decreased as age increased. In this present study, 10- to 15- year-old Himalayan birch are considered as juvenile wood in which the woods contained more than 50% sapwood. Based on previous studies on juvenile wood, normally, juvenile wood contains more than 50% sapwood, *e.g.*, in 10-year-old *Azadirachta excelsa* (sentang) (Nordahlia *et al.* (2014), 8-year-old Malaysian-grown teak (Lim and Gan 2000), and 13-year old teak (Bhat 1995).

Table 2. Sapwood-Heartwood Ratio Between the Age Groups

Age	% of Sapwood
10	58.3
15	59.1
20	38.6
25	35.1

Microscopic Features

The following description of Himalayan birch is based on microscopic features of a 10- to 25-year-old tree. **Cross-section (Fig. 1):** Growth rings are present in the cross-section, marked by 2 to 4 rows of radially flattened cells. Wood is diffusely porous, with vessels that are solitary, in radial multiples of 2 to 3, and in clusters. The size of the vessels varies with age, ranging from 88 to 132 μm . There are scalariform perforation plates present. The axial parenchyma diffuses and is marginal. **Tangential section (Fig. 2):** Rays are 2- to 5-seriate, the average ray height varies with age, ranging from 328 to 450 μm . **Radial section (Fig. 3):** All ray cells procumbent and non-septate fibres are present.

The anatomical properties of Himalayan birch at four different ages are tabulated in Tables 3 and 4. The fibre length of either sapwood or heartwood increased as the tree grew older. However, after 10 years, the fibre length at sapwood reached a plateau. The highest value obtained for heartwood at age 25-year-old was 1673 μm . From the result obtained, Himalayan birch of all ages studied showed longer fibre than *Hevea brasiliensis* (Naji *et al.* 2013) and *Eucalyptus grandis* (Palermo *et al.* 2015). The diameter and lumen of Himalayan birch fibres ranged from 29 to 33 μm and 18 to 23 μm , respectively.

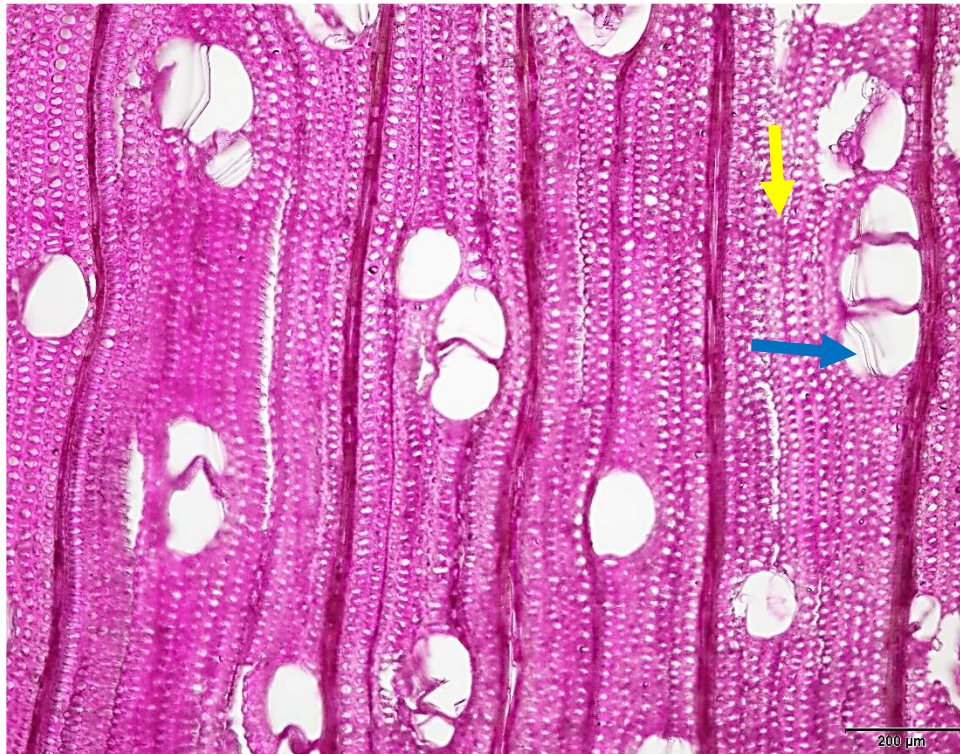


Fig. 1. Cross-section: Growth rings present, marked by 2 to 4 rows of radially flattened cells (yellow arrow). Wood diffuse-porous, vessels solitary and in radial multiples of 2 to 3, scalariform perforation plate (blue arrow)

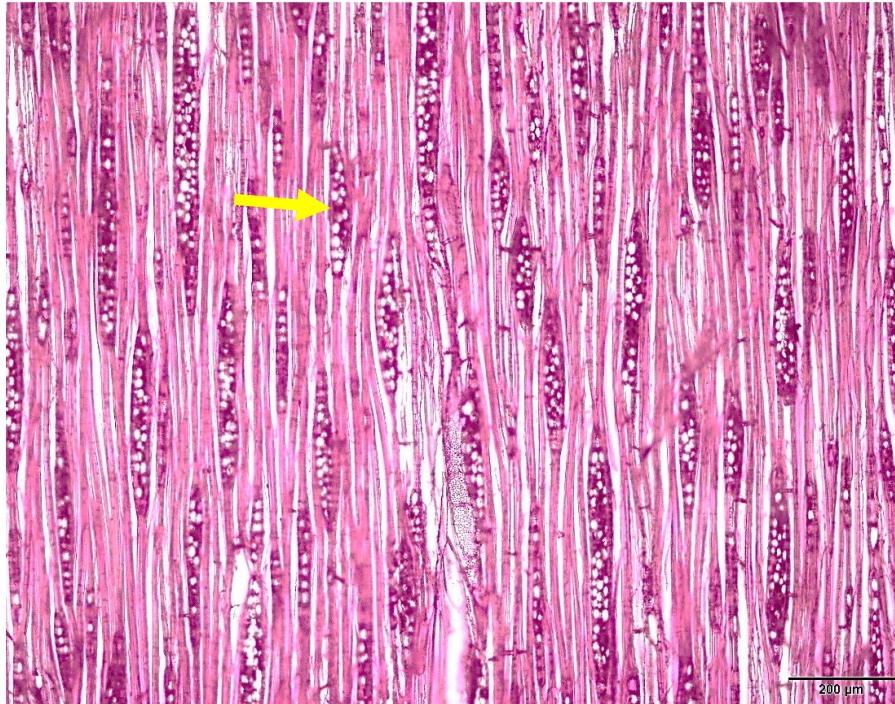


Fig. 2. Tangential section: Rays 2- to 5-seriate (arrow)

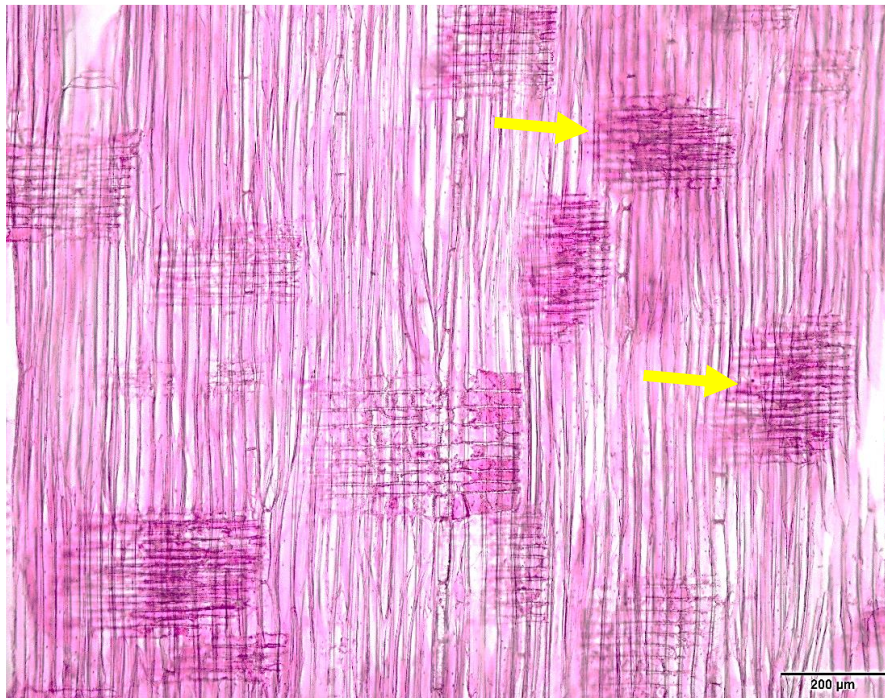


Fig. 3. Radial section: All ray cells procumbent (arrows) and non-septate fibres present

Table 3. Fibre Morphology of Himalayan birch at Four Different Ages

Age (years)	Fibre Length (μm)		Fibre Diameter (μm)		Fibre Lumen Diameter (μm)		Fibre Wall Thickness (μm)	
	Swd	Hwd	Swd	Hwd	Swd	Hwd	Swd	Hwd
10	1823 ^a (312)	1363 ^a (201)	32.5 ^a (6.1)	31.0 ^a (4.8)	24.0 ^a (6.5)	19.8 ^a (3.4)	4.2 ^a (0.5)	5.6 ^a (1.9)
15	1829 ^a (198)	1480 ^a (135)	32.4 ^a (5.0)	30.0 ^a (3.0)	19.7 ^a (3.4)	18.2 ^a (3.5)	6.4 ^b (0.8)	5.8 ^a (0.6)
20	1823 ^a (153)	1653 ^b (302)	32.3 ^a (4.6)	31.0 ^a (4.0)	19.0 ^a (4.6)	18.8 ^a (2.3)	6.7 ^b (0.5)	6.0 ^a (0.5)
25	1844 ^a (272)	1673 ^b (211)	33.1 ^a (5.1)	30.0 ^a (5.2)	19.02 ^a (4.2)	18.2 ^a (4.5)	7.0 ^b (0.8)	6.1 ^a (0.5)
¹ <i>Betula alnoides</i> (Himalayan birch)	900-1600		-		-		-	
² <i>Hevea brasiliensis</i>	1249		29.6		20.3		4.7	
³ <i>Eucalyptus grandis</i>	1110		22		14		4.0	

¹ InsideWood. 2004-onwards. Published on the Internet. <http://insidewood.lib.ncsu.edu/search>

² Naji *et al.* (2013)

³ Palermo *et al.* (2015)

Note: Swd: Sapwood, Hwd: Heartwood; Values in parentheses are standard deviations. Cell values differing by a letter (^{a, b, c}) in the superscript in each column are significantly different at $p \leq 0.05$.

Table 4. Anatomical Properties, Runkel Ratio, and Slenderness Ratio of Himalayan birch at Four Different Ages

Age (years)	Vessel Diameter (μm)		Ray Height (μm)		Runkel Ratio		Slenderness Ratio	
	Swd	Hwd	Swd	Hwd	Swd	Hwd	Swd	Hwd
10	116.5 ^a (12.1)	95.5 ^a (6.4)	384.3 ^a (50.4)	379.6 ^a (53.3)	0.37 ^a (0.11)	0.56 ^a (0.24)	56.4 ^a (14.9)	43.9 ^a (8.6)
15	120.2 ^a (13.6)	99.9 ^a (8.4)	424.9 ^b (49.0)	418.7 ^b (40.7)	0.67 ^b (0.09)	0.63 ^a (0.13)	56.4 ^a (3.9)	49.8 ^a (5.9)
20	126.1 ^{ab} (15.9)	101.2 ^a (9.7)	446.9 ^b (78.2)	425.4 ^b (83.2)	0.70 ^b (0.17)	0.64 ^a (0.1)	56.4 ^a (3.9)	54.0 ^b (9.4)
25	132.1 ^{bc} (16.5)	108.1 ^{ab} (14.8)	449.7 ^b (70.3)	437.9 ^b (87.3)	0.74 ^c (0.20)	0.67 ^a (0.14)	55.8 ^a (3.1)	55.1 ^b (2.39)
¹ <i>Betula alnoides</i> (Himalayan birch)	100-200		350-800		-		-	

¹ InsideWood. 2004-onwards. Published on the Internet. <http://insidewood.lib.ncsu.edu/search>

Note: Swd: Sapwood, Hwd: Heartwood;

Values in parentheses are standard deviations. Cell values differing by a letter (^{a,b,c}) in the superscript in each column are significantly different at $p \leq 0.05$.

In contrast, the vessel diameter and ray height significantly increased with the age (Table 4). The anatomical properties of Himalayan birch of all ages were larger in the sapwood compared to heartwood. Sapwood generally has higher anatomical properties than the heartwood. This is because sapwood is the actively conducting portion of the stem in which parenchyma cells are still alive and metabolically active. Meanwhile, heartwood

is the dead, inner wood portion of a stem that often accounts for the majority of its cross-section (Wiedenhoef 2010).

Table 4 also shows the Runkel ratio and slenderless ratio for Himalayan birch. The highest mean value was observed at the age of 25 years, which was 0.74 and 0.67 for sapwood and heartwood, respectively. The Runkel ratio for Himalayan birch was less than 1 (< 1) until the age of 25. Fibre with a Runkel ratio less than 1 is considered fine raw material and is suitable for the papermaking industry. Fibres with a Runkel ratio less than 1 (< 1) produce high-quality pulp and paper because they have a large surface area for bonding (Jang and Seth 1998; Kiaei 2011). This species' slenderness ratio is greater than 33, which indicates that it will provide better forming and well-bonded paper (Xu *et al.* 2006; H'ng *et al.* 2016; Nordahlia *et al.* 2022).

Physical and Mechanical Properties

Table 5 summarises the results of physical and mechanical properties. Based on the findings, the density of Himalayan birch increases with age, with values of 432, 538, 552, and 578 kg/m³ for 10-, 15-, 20-, and 25-year-olds, respectively. The density of Himalayan birch was significantly different between the ages of 10 and 15, but not between the ages of 15 and 25. There is no significant difference in moisture content and volumetric shrinkage observed.

Table 5. Physical and Mechanical Properties of Himalayan birch

Age (years)	MC (%)	Oven-Dry Density (kg/m ³)	Volumetric Shrinkage (%) Air-dry to Oven-dry	MOR (N/mm ²)	MOE (N/mm ²)	Compression Parallel to Grain (N/mm ²)
10	9.27 ^a (0.64)	431.8 ^a (55.1)	5.2 ^a (0.5)	93.4 ^a (9.3)	9378 ^a (1186)	40.9 ^a (5.3)
15	9.71 ^a (0.45)	538.5 ^b (29.6)	5.3 ^a (0.5)	115.9 ^b (10.3)	11591 ^b (1523)	55.5 ^b (6.1)
20	9.44 ^a (0.70)	551.6 ^b (25.0)	5.2 ^a (0.4)	108.2 ^b (5.8)	11679 ^b (607)	55.8 ^b (3.6)
25	9.88 ^a (0.69)	578.0 ^b (15.1)	5.2 ^a (0.3)	126.8 ^c (13.2)	12124 ^b (1010)	58.57 ^b (6.0)
¹ <i>Betula alnoides</i> (Himalayan birch)	-	647.0	-	107.6	12337	50.23
² <i>Betula alleghaniensis</i>	-	690	-	114.5	13860	-
³ <i>Hevea brasiliensis</i>	-	503-533	-	81.3	8564	33.6
⁴ <i>Eucalyptus grandis</i>	-	517	-	84	8412	52
⁵ <i>Pinus yunnanensis</i>	-	-	-	52.6	7428	31.1
⁶ <i>Cunninghamia lanceolata</i>	-	-	-	63.9	7511	46.2

¹ Sun *et al.* (2006), ² Eric (2015) ³ Naji *et al.* (2013), ⁴ Palermo *et al.* (2015), ⁵ Liao *et al.* (2013),

⁶ Zhao and Qiu (2021)

Values in parentheses are standard deviations. Cell values differing by a letter (a,b,c) in the superscript in each column are significantly different at p ≤ 0.05.

The density of Himalayan birch from this study was lower than what was reported by Sun *et al.* (2006) (*Betula alnoides*) and Eric 2015 (*B. alleghaniensis*). However, the value was higher than other plantation species such as *Hevea brasiliensis* (Naji *et al.* 2013) and *Eucalyptus grandis* (Palermo *et al.* 2015). Table 5 also summarized some information from other studies for comparison.

Mechanical properties, such as bending strength (MOR, MOE) and compression parallel to grain, of Himalayan birch increased with age. At 25 years old, the highest values for MOR, MOE, and compression parallel to the grain were 126 N/mm², 12124 N/mm², and 58.6 N/mm², respectively. There is a significant difference in MOR between 10 and 15 years old, and a highly significant difference between 25 years old.

Figure 4, 5, and 6 shows the relationship between the age of Himalayan birch and mechanical strength (MOR, MOE, compression). The regressions lines that were fitted to data indicate a positive relationship between age and mechanical strength. The coefficients of determination (R^2) for MOR, MOE and compression strength were 0.72, 0.76 and 0.74, respectively.

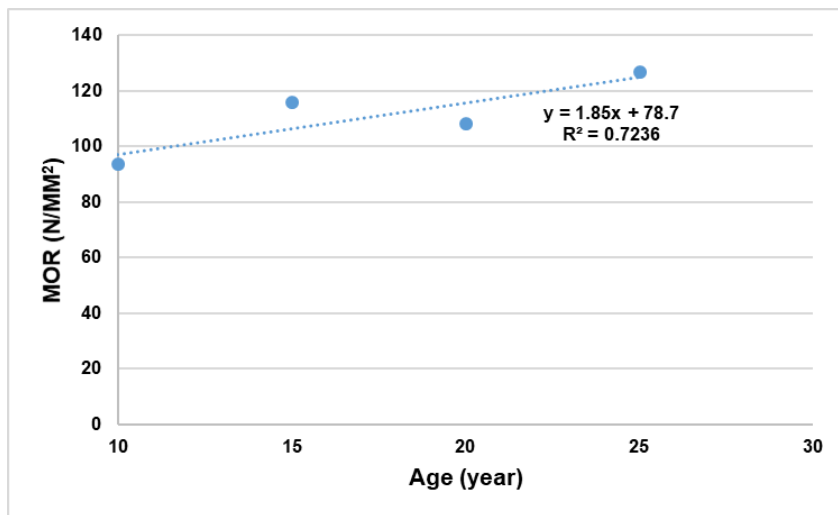


Fig. 4. Relationship between age and MOR of Himalayan birch

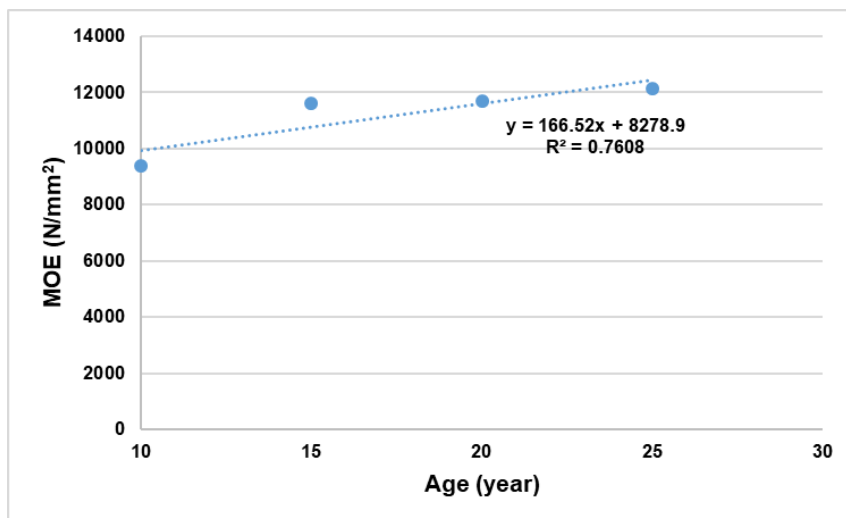


Fig. 5. Relationship between age and MOE of Himalayan birch

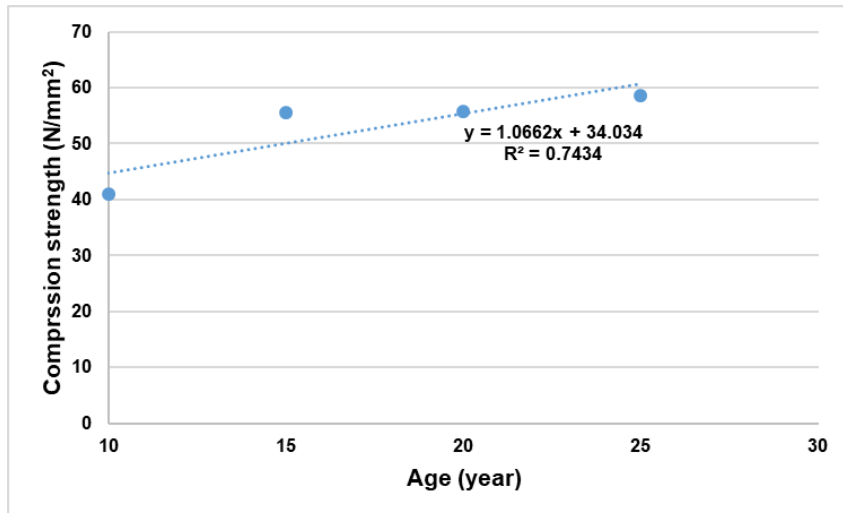


Fig. 6. Relationship between age and compression strength of Himalayan birch

This difference is caused by the increased density of older trees (Bijak and Lachowicz 2021). Hassani *et al.* (2022) found that the mechanical properties of *Populus nigra* increased when the age of tree increased. They related it with the fiber length and cell wall thickness, which affect the increasing of density of the wood. Similar findings were also obtained from the research conducted by Bijak and Lachowicz (2021).

The findings in this study also revealed that the mechanical properties of 20-year-old Himalayan birch are almost similar to that of mechanical properties of 19-year-old Himalayan birch reported by Sun *et al.* (2006). As comparisons, the average values of MOR, MOE, and compression parallel of Himalayan birch in this study also were higher than other plantation species for example *Hevea brasiliensis* (Naji *et al.* 2013), *Eucalyptus grandis* (Palermo *et al.* 2015), *Pinus yunnanensis* (Liao *et al.* 2013), and *Cunninghamia lanceolata* (Zhao and Qiu 2021).

Correlation Analysis Between Fibre Morphology and Mechanical Properties

Table 6 shows the results of the correlation between fibre morphology and mechanical properties. A very strong correlation was observed between fibre morphology with MOR, where the r value is more than 80 ($r \geq 80$). A strong correlation was observed between fibre morphology with MOE and compression parallel to grain, where the r value is 0.60 to 0.79 (r : 0.60 to 0.79).

Table 6. Correlation Factors Influencing MOR, MOE, and Compression of Himalaya Birch

Correlated Parameters	Regression Coefficient (r)		
	MOR	MOE	Compression Strength
Fibre length x	0.82	0.69	0.74
Fibre diameter x	0.80	0.69	0.75
Fibre lumen x	0.83	0.68	0.74
Fibre wall thickness x	0.82	0.70	0.74

Based on the obtained results, mechanical properties were highly correlated with the fibre morphology in Himalayan birch. This was in good agreement with the conclusions reached by Hamdan *et al.* (2020) and Adeniyi *et al.* (2013) who also reported that fibre structure was the factor that primarily affected the mechanical properties of wood.

CONCLUSIONS

1. The age of Himalayan birch trees affects the fibre length (heartwood), fibre wall thickness (sapwood), vessel diameter, and ray height.
2. This species is suitable as a raw material for the pulp and paper industry as shown by its suitable anatomical properties based on Runkel and Slenderness ratio.
3. The density, bending strength and compression strength of the Himalayan birch increased as the age increased.
4. Based on the result obtained, 15-, 20-, and 25-year-old timber of Himalayan birch is suitable to use for parquet, furniture, and other wood based products.
5. Finally, plantation-grown Himalayan birch have the potential to be a raw material for the timber industry.

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