

Article

Comparison of Physical and Mechanical Properties of Beech and Walnut Wood from Iran and Georgian Beech

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Abstract: Beech (*Fagus orientalis* Lipsky) forests in Iran are one of the most important sources of the hardwood species used for lumber, furniture, and interior object design due to its hardness, wear resistance, strength, and excellent bending capabilities. Furthermore, Iran is third most important country for walnut wood production after China and United States. Therefore, in this study, we compared specific mechanical properties between beech wood obtained from Sangdeh (Iran) and Georgia and four different kinds of walnut woods in Iran. Physical and mechanical tests were performed according to ISO 3129 (2012) and ASTM (D143-14) standards. The moisture content of all samples was 12% during mechanical tests. The mean dry density of Sangdeh and Georgian beech obtained was 0.61 and 0.65 g/cm³, respectively, while the mean dry density of Noor, Shahrekord, Mashhad, and Mako walnut woods measured 0.62, 0.59, 0.62, and 0.57 g/cm³, respectively. The results showed significant differences among the properties of the Sangdeh and Georgian species and the four different walnut tree woods. Overall, the obtained strengths of Georgian timber were higher than that of the Iranian beech, which was attributed to the higher density of Georgian timber. Furthermore, due to the higher density of the walnut species in the Noor and Mashhad regions, the measured mechanical strengths of these trees were higher than those of other walnut species. The obtained results provide relevant information to determinate the future applications of each wood source.

Keywords: beech; density; shrinkage; static bending; walnut

1. Introduction

Wood and wood products are some of the most important materials that have been traditionally used for building constructions, veneers, flooring, boatbuilding, furniture, cabinetry, musical instruments, plywood, and turned objects [1,2]. To date, wood is still an essential material for several applications due to its mechanical properties, workability, and thermal isolation properties. However, wood may also have some negative properties, including low dimension stability related to weather changes. Additionally, some mechanical properties such as strength and hardness are not identical in all directions of the grain, which can be aggravated by internal defects [3]. Thus, the use of wood for specific applications needs deep knowledge about its physical and mechanical properties. In this context, wood density is one of the most important features in the selection of trees and could be

considered the main factor for understanding wood quality. For instance, some studies have proposed that the average density of beech wood is higher than 0.7 g/cm^3 [1,4].

The Hyrcanian region, located south of the Caspian Sea, covers $\sim 50,000 \text{ km}^2$ of the northern provinces in Iran. Due to the characteristic climate with high precipitation and the fertility of the soil, this region is well-known for plant diversity and fast growth. In particular, Iranian beech is one of the main inhabiting species in this area, which occupies 30% of the surface [5]. Although the beech wood species has a moderate durability against microorganisms [6–8], it is one of the main wood sources in many European countries [1,4,9–12], and this wood is mostly used in plywood, veneer, furniture, and construction [13] and has high potential for pulping and bio-pulping [14].

Walnut tree species are cultivated in many countries around the world due to their strength and beautiful color patterns [15–18]. Among these properties, the Persian walnut produces edible fruits which is being planted in many countries like southeastern Europe and western Central Asia [16,17,19]. This wood is mainly used for furniture, construction panels, and veneer products [15,20,21]. On the other hand, Iran is the third most important country in terms of walnut wood production, after China and the United States [18].

Due to the traditional use of wood species for several applications worldwide, it is necessary to acquire specific knowledge of the physical and mechanical properties of wood, such as the modulus of elasticity (MOE), modulus of rupture (MOR), and other strength properties with great significance for wood products and construction [22]. Nowadays, many diverse methods are used to evaluate wood properties such as color measurement [23], tomography [24] and thermography [25,26], near-infrared (NIR) spectroscopy [27,28], and wave propagation methods [29,30]. Some studies have investigated the physical and mechanical properties of beech wood, such as the modulus of rupture, modulus of elasticity, shear strength parallel to the grain, density, and shrinkage [10,11,31–35]. For instance, Saurat and Gueneau [36] reported that the mechanical strength of European beech was higher compared to that of American beech wood. Regarding walnut wood, research has also been conducted on the physical and mechanical properties of this valuable species, such as density, shrinkage, modulus of rupture, modulus of elasticity, shear strength parallel to the grain, compression strength parallel to the grain, and tensile strength parallel to grain [20,21,37–39].

However, deep characterization of Iranian wood sources has not been performed to date. Therefore, in this study, we have collected wood samples from walnut and beech species from Iran and imported Georgian beech from Georgia and compared the mechanical and physical properties in order to define the potential applications of these wood species.

2. Materials and Methods

Three imported Georgian beech timbers (*Fagus orientalis*) were used with equal dimensions of $6.3 \times 25 \times 600 \text{ cm}$. Beech trees of the northern forests in Iran (Sangdeh region) at similar sea level were selected and cut at $\sim 200 \text{ cm}$ height from the ground level (Table 1). Walnut trees were selected from four different regions in Iran, including Noor (north), Shahrekord (center), Mashhad (northeast), and Mako (northwest). The relevant information for each tree, such as soil characteristics and age, is also reported (Table 1).

The extracted wood was prepared according to the international standards ISO 3129 (2012) and ASTM (D143-14), as shown in Table 2.

Table 1. Main features of the selected trees and areas where wood samples were collected.

Characteristics	Noor	Shahrekord	Mashhad	Mako	Sangdeh
Tree species	Walnut (<i>Juglans regia</i>)	Beech (<i>Fagus orientalis</i>)			
Height from sea level (m)	1200	1920	1813	1555	1800
Soil	Loam soil	Loam soil	Silt loam	Loam soil	Sandy soil
Coordinates (UTM) ¹	36°34'02.8" N/52°03'23.0" E	32°20'16.4" N/50°50'57.1" E	36°13'32.5" N/59°37'15.2" E	39°16'52.6" N/44°28'01.1" E	36°04'05.9" N/53°13'50.4" E
Mean tree age (years)	43	37	35	31	146
Mean DHB ² (cm)	39.5	35	31.5	30	45

¹ UTM: Universal Transverse Mercator. ² DBH: diameter at breast height.

Table 2. Experimental test methods and characteristics of the studied wood samples.

Standard	Test Method	Direction	Specimen Size (mm)	Loading Rate (mm min ⁻¹)
ISO 3129	Density, shrinkage	-	20 × 20 × 25	-
	Bending	-	25 × 25 × 410	1.3
ASTM D143	Compression	Parallel to the grain	50 × 50 × 200	0.3
	Shear	Parallel to the grain	50 × 50 × 63	0.6
		Parallel to the grain	25 × 25 × 460	0.9
	Tensile	Perpendicular to the grain	50 × 50 × 63	2.5
		Screw withdrawal strength	Tangential	50 × 50 × 150
	Radial			
	Impact bending	Radial	20 × 20 × 280	-

The obtained timber was cut according to an ISO standard to measure the physical properties, and the rest of the sheared wood was cut to reach the dimensions required for mechanical testing. To measure shrinkage, the samples were first immersed in a container full of deionized water for a week until the wood was completely saturated, and after measuring their dimensions and weight with a 0.01-gram scale, the samples were placed in an oven at different temperatures (45, 55, 65, 75, 85, and 103 °C) for 24 h for each degree until they were completely dried. The purpose of these different temperatures was to dry the samples slowly and without tension. After that, we obtained the dry weight of the samples, and shrinkage was measured after measuring their dimensions. For mechanical tests, samples were placed in rooms with controlled conditions (20 °C and 65% relative humidity) to reach a moisture content of 12%. Then, by utilizing the related standard, the parts were cut. After that, mechanical tests were performed with a SANTAM 150 device and the mechanical properties were measured (Figure S1). All samples were kept at a constant moisture content of about 12% during the mechanical tests. Statistical analysis was performed using SPSS software version 16 and an ANOVA and *t*-test were used for data analysis.

3. Results and Discussion

3.1. Physical Properties

The results of the physical and mechanical properties of beech and walnut wood are shown in Table 3. As can be seen for walnut wood, a significant difference was observed between the dry density, radial shrinkage, tangential shrinkage, and volumetric shrinkage. Moreover, significant differences between Iranian and Georgian beech were also found in terms of physical properties except radial shrinkage. A significant difference between

these species was reported (Table 4). The significant differences in the physical properties of the wood species from the four different regions and between the two types of beeches are mainly due to the density of the wood, because the density directly affects most of the physical and mechanical strengths of the wood. Moreover, growth conditions and environmental factors, especially altitude, weather, and the age of the tree, may cause changes in wood properties [12].

Table 3. Physical properties of the studied wood species.

Properties	Noor Walnut (<i>Juglans regia</i>)	Shahrekord Walnut (<i>Juglans regia</i>)	Mashhad Walnut (<i>Juglans regia</i>)	Mako Walnut (<i>Juglans regia</i>)	Sangdeh Beech (<i>Fagus orientalis</i>)	Georgia Beech (<i>Fagus orientalis</i>)
Dry density (g/cm ³)	0.62 {0.03} ¹ (120) ²	0.59 {0.03} (120)	0.625 {0.02} (120)	0.58 {0.02} (120)	0.61 {0.12} (327)	0.65 {0.027} (38)
Axial shrinkage (%)	0.192 {0.061} (120)	0.181 {0.195} (120)	0.223 {0.083} (120)	0.206 {0.101} (120)	0.32 {0.15} (327)	0.58 {0.243} (38)
Radial shrinkage (%)	6.24 {0.881} (120)	5.68 {0.595} (120)	6.225 {0.408} (120)	5.813 {0.455} (120)	5.359 {0.31} (327)	5.47 {0.403} (38)
Tangential shrinkage (%)	10.7 {1.124} (120)	8.91 {1.155} (120)	9.779 {0.726} (120)	8.781 {0.714} (120)	10.649 {0.84} (327)	12.15 {0.405} (38)
Volumetric shrinkage (%)	17.04 {1.32} (120)	14.54 {1.23} (120)	16.26 {1.06} (120)	15.42 {0.71} (120)	16.433 {0.71} (327)	18.73 {0.384} (38)

¹ The numbers in curly brackets indicate standard deviation. ² The numbers in parentheses indicate the number of samples used.

Table 4. Statistical analysis of physical properties.

Type	Dry Density	Axial Shrinkage	Radial Shrinkage	Tangential Shrinkage	Volumetric Shrinkage
ANOVA of four walnut	0.000	0.122 ^{ns}	0.031	0.000	0.000
<i>t</i> -test of beech	0.000	0.000	0.128 ^{ns}	0.000	0.000

Significant difference at level of 5%. ^{ns} not significant.

The results for the dry density of wood from the Noor and Mashhad regions were 0.62 and 0.625 g/cm³, respectively, which are close to the values reported by Bachtiar et al. [20] of 0.65 g/cm³ for walnut woods in Eastern Europe and by Bachtiar et al. [39] of 0.67 g/cm³ for walnut woods in the Caucasus. Furthermore, the results for the dry density of wood from the Shahrekord and Mako regions were 0.59 and 0.58 g/cm³, respectively, which are similar to the value reported by Castro et al. [38] of 0.52 g/cm³ for walnut wood in Italy. However, some previous studies have reported values above 0.7 g/cm³ for the dry density of walnut wood [21,37]. The values of radial, tangential, and volumetric shrinkage of the four types of walnut woods in this study were approximately equal to those reported by Castro et al. [38].

The dry density values of the beech wood collected from Sangdeh and Georgia were 0.61 and 0.65 g/cm³, respectively. These results are similar to the properties reported by Akrami et al. [4] for *F. sylvatica* in Germany (0.64 g/cm³), for oriental beech in Iran [34] (0.59 g/cm³), and for *F. sylvatica* [35] and beech in the USA (0.64 g/cm³) [33]. However, several authors have demonstrated slightly higher dry density values (0.68 g/cm³) for beech trees (*F. sylvatica*) grown in Europe [1,10,11,31]. Overall, the obtained result for radial shrinkage in this research was similar to that of Kretschmann [33]. In addition, the tangential and volumetric shrinkage results of the Sangdeh beech obtained in the current study (10.65% and 16.43%, respectively) were lower than the findings described by Kretschmann [33], where the high shrinkage was attributed to the lower density of Sangdeh beech. On the other hand, the tangential and volumetric shrinkage results of the Georgian timbers were similar to the results reported by Lo Monaco et al. [31].

3.2. Mechanical Properties

The results of the mechanical properties of the beech and walnut wood are shown in Table 5. As can be seen for walnut wood, a significant difference was observed between bending strength, modulus of elasticity, and shear and tensile strength parallel to grain. In addition, significant differences between Iranian and Georgian beech were found for all mechanical properties. A significant difference between these species was reported (Table 6). The significant differences in the mechanical properties of the wood species from the four different regions and between the two types of beeches are mainly due to the different density of wood.

Table 5. Mechanical properties of the studied wood species.

Properties	Noor Walnut (<i>Juglans regia</i>)	Shahrekord Walnut (<i>Juglans regia</i>)	Mashhad Walnut (<i>Juglans regia</i>)	Mako Walnut (<i>Juglans regia</i>)	Sangdeh Beech (<i>Fagus orientalis</i>)	Georgia Beech (<i>Fagus orientalis</i>)
Bending strength (MPa)	96.23 {7.68} ¹ (18) ²	91.13 {6.99} (18)	100.54 {7.10} (18)	87.61 {5.06} (18)	88.17 {1.19} (46)	99.01 {5.21} (16)
Modulus of elasticity (MPa)	10092 {6.21} (18)	10084 {5.91} (18)	10049 {8.71} (18)	7504 {5.94} (18)	9308 {8.43} (46)	11224 {7.96} (16)
Compression parallel to the grain (MPa)	36.07 {4.25} (9)	32.47 {4.14} (9)	37.91 {4.58} (9)	33.88 {4.25} (9)	42.05 {6.62} (9)	57.05 {4.13} (16)
Shear strength parallel to the grain (MPa)	10.73 {0.74} (9)	9.92 {1.32} (9)	9.15 {0.41} (9)	8.95 {0.71} (9)	8.412 {0.65} (14)	10.47 {1.45} (16)
Tensile strength parallel to the grain (MPa)	131.4 {5.56} (9)	124.7 {7.48} (9)	127.97 {8.34} (9)	125.83 {4.65} (9)	82.51 {2.42} (12)	131.15 {7.10} (16)
Tensile strength perpendicular to the grain (MPa)	3.15 {0.56} (9)	3.1 {0.39} (9)	-	-	1.99 {0.39} (14)	3.71 {0.44} (16)
Screw withdrawal strength tangential (N)	4061 {3.53} (9)	3916 {3.77} (9)	4031 {3.86} (9)	3685 {4.22} (9)	4466 {4.78} (20)	-
Screw withdrawal strength radial (N)	4151 {4.12} (9)	4123 {4.61} (9)	4218 {2.63} (9)	3915 {3.98} (9)	4566.2 {4.42} (20)	-
Impact bending (KJ/m ²)	120.3 {13.89} (9)	110.1 {7.21} (9)	-	-	129.9 {8.72} (10)	110.81 {1.37} (16)

¹ The numbers in curly brackets indicate standard deviation. ² The numbers in parentheses indicate the number of samples used.

Table 6. Statistical analysis of mechanical properties.

Type	Bending Strength	MOE	Compression	Shear	Tensile Parallel	Tensile Perpendicular	Screw in Tangential	Screw in Radial	Impact Bending
ANOVA of four walnut trees	0.001	0.000	0.082 ^{ns}	0.001	0.025	0.825 ^{ns}	0.127 ^{ns}	0.618 ^{ns}	0.083 ^{ns}
<i>t</i> -test of beech	0.000	0.000	0.000	0.000	0.000	0.000	-	-	0.035

Significant difference at level of 5%. ^{ns} not significant.

Accurate identification of structural performance and reliability, especially for construction materials, is needed for wood products. Therefore, the bending strength and the modulus of elasticity are two crucial mechanical properties that should be carefully considered and related to the wood density [40]. The average bending strength for the two types of beech wood in this study was close to the values reported by Kretschmann [33], Lo Monaco et al. [31], and Simsek et al. [32] of 103, 108.4, and 104.1 N/mm², respectively. On the other hand, Campean et al. [35] and Pöhler et al. [11] reported higher results (120 and 127 N/mm², respectively). In our study, the average modulus of elasticity was lower than the value of 12900 N/mm² reported by Campean et al. [35] and of 13006 N/mm² reported by Pöhler et al. [11]. In this study, the obtained compression strength parallel to the grain of Sangdeh beech wood was 42.05 N/mm², which was lower than the values reported by Campean et al. [35], Lo Monaco et al. [31], and Simsek et al. [32] (64, 54.4, and 72.7 N/mm²,

respectively). The average compression strength parallel to the grain of Georgian beech was similar to that of Italian beech at 54.4 N/mm^2 , as reported by Lo Monaco et al. [31]. The average shear strength values parallel to the grain of Sangdeh and Georgian beech were slightly lower than the result of 12.4 N/mm^2 achieved by Campean et al. [35] and of 13.3 N/mm^2 by Taj et al. [34]. In this study, the tensile strength values parallel and perpendicular to the grain of Sangdeh beech wood were 82.51 and 1.99 N/mm^2 , respectively, which were lower than the values reported by Campean et al. [35]. We attributed the lower values obtained for the mechanical strengths of Sangdeh beech to the low density of the collected wood. The average value of tensile strength parallel and perpendicular to the grain of Georgian beech was much higher than the results reported by Campean et al. [35]. Using the ASTM (D143) standard, we measured tangential and radial screw withdrawal strength, measured as 4466 and 4566.2 N , respectively. The acquired value of tangential screw withdrawal strength of this study was higher than 2690 N , as reported by Taj et al. [34]. Impact bending was also performed, but no similar research was found to compare from previous studies.

The mean value of the bending strength from walnut wood was approximately equal to the value of 99.03 N mm^2 reported by Guler and Dilek [37] for walnut in Turkey. In this study, the values obtained for the modulus of elasticity from walnut trees in the Noor, Shahrekord, and Mashhad regions were exactly equal to the values reported by Bachtiar et al. [39] and Guler and Dilek [37] (10217 and 10062.7 N/mm^2 , respectively). However, the mean value for the modulus of elasticity from walnut wood in Mako was 7504.21 N/mm^2 . This mean value was much lower than that of other walnut species, which was attributed by the authors to the lower density of walnut wood in Mako. The compression strength parallel to the grain was much lower than the value of 47 N/mm^2 reported by Bachtiar et al. [20], which was attributed by the authors to the lower density of Iranian walnut wood. In addition, the values of the shear strength parallel to the grain in this study were slightly lower than the value of 13.3 N/mm^2 reported by Bachtiar et al. [21] for walnut woods in the Caucasus. In this study, tensile strength tests parallel and perpendicular to the grain were also performed, and the tensile strength parallel to the grain measured was higher than the value of 89 N/mm^2 reported by Bachtiar et al. [20].

Using the ASTM standard (D143-14), in this study, screw withdrawal strength in both tangential and radial directions was measured, but no significant difference was observed between the four regions. In addition, an impact bending test in the radial direction was also performed, but unfortunately, no similar research was found to compare these two strengths of walnut wood. Therefore, the characterization of Iranian beech and walnut woods showed that the mechanical properties of woods from the Noor, Shahrekord, and Mashhad regions were higher than those of the walnut wood collected in Mako. Furthermore, the comparison between the physical characteristics of both types of beech demonstrated that the mechanical properties of Sangdeh beech were poorer than those of the Georgian beech. Although the mechanical properties of Noor and Mashhad walnut woods were better than those of the Sangdeh beech, its use for building construction is recommended due to the high economical value of this special wood that has beautiful color patterns preferred for furniture, construction panels, and veneer products.

4. Conclusions

The goal of this study was to investigate the physical (shrinkage and density) and mechanical properties (bending strength, modulus of elasticity, compression parallel to the grain, shear strength parallel to the grain, tensile strength parallel and perpendicular to the grain, screw withdrawal strength, and impact bending) of Iranian and Georgian beech and walnut wood. The results indicated that beech from Sangdeh has a medium resistance, lower than that of European beech. These lower values of the mechanical and physical properties of Iranian beech were attributed to the lower density of the species, weather, and geographic conditions. Walnut wood from Noor and Mashhad showed the highest strength compared to the walnut trees in the two other regions studied. Overall,

these results demonstrate that Iranian wood sources have comparable properties to wood sources from other countries. Therefore, beech timber can be recommended for building construction and interior materials design, while walnut wood can be used for furniture, construction panels, and veneer products.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/f12060801/s1>, Figure S1: SANTAM 150 equipment device mechanical tests and measures mechanical properties.

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