



The Impact of Forest Thinning on Physical and Mechanical Properties of Beech Wood (*Fagus sylvatica* L.) in Albania

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Abstract: This study explores how forest thinning influences both the radial growth of trees as well as physical and mechanical characteristics of beech wood (*Fagus sylvatica* L.) across different ecological sites in Albania. The research was carried out in three representative regions by comparing forest stands that had not been managed with thinning to those where thinning practices were applied. A total of 18 experimental plots were examined, focusing on annual growth, wood density, and key mechanical properties such as static bending strength (MOR) and compression strength parallel to the grain, following ISO standards. The results demonstrate that thinning exerts a pronounced positive effect on annual growth, yielding nearly a twofold increase in mean annual ring width relative to unthinned stands. At the same time, wood from unthinned plots tended to exhibit higher density, whereas thinned stands showed a moderate reduction in density. Statistical analyses highlighted that site conditions play a major role in shaping wood density and mechanical performance, underlining the importance of local environmental and silvicultural interventions. Mechanical properties, including bending and compression strength, were generally slightly higher in unthinned plots, although differences within the same site were often small and not statistically significant.

Overall, the results suggest that when thinning is applied in a controlled manner, it can boost volume production and improve stem growth without noticeably reducing the mechanical quality of beech wood. These insights emphasize the importance of adapting forest management strategies to local conditions in order to achieve a balanced, sustainable use of European beech forests that meets both productivity and quality goals.

Keywords: beech wood, thinning, density, mechanical strength.

Introduction

Beech wood (*Fagus sylvatica* L.) is one of the most important deciduous forest species in Europe, particularly in the Balkan region, where it occupies a substantial area of both natural and managed forests. Beech forests represent a key component of the forest landscape in Southeastern Europe, including Albania. They play an important ecological role in maintaining biodiversity, ecosystem stability, and soil protection. In addition to their ecological functions, beech forests are also an important economic resource for the wood industry, as beech wood is widely used in the production of furniture, flooring, and high-value structural elements [1,2].

Wood quality is determined by a range of biological and environmental factors that directly influence its anatomical structure and physical–mechanical properties. In the scientific literature, the main parameters of wood quality include physical properties such as density, moisture content, shrinkage, and dimensional stability, as well as mechanical properties such as bending strength (MOR), compression strength, and modulus of elasticity (MOE) [3,4]. These characteristics depend not only on the genetic traits of the species but also on growth conditions and silvicultural practices applied during stand development.

One of the main silvicultural interventions in the management of beech forests is thinning. Thinning is a practice aimed at reducing tree density within a given forest area by removing weaker individuals to promote the growth of the remaining trees. This intervention reduces competition for key growth resources such as light, water, and nutrients, thereby increasing diameter growth rates and improving stand stability [5,6]. However, the effects of thinning are not limited to the productive and structural aspects of forests but also extend to the technological quality of wood. Changes in growth conditions following thinning may alter annual ring formation, the proportion of earlywood to latewood, and the density of wood tissues. As a result, thinning can lead to significant changes in the physical–mechanical properties of wood [7,8].

Several studies have shown that rapid diameter growth following intensive thinning may be associated with reduced wood density, which can negatively affect mechanical strength [9]. Conversely, moderate thinning can contribute to improved stem quality by promoting the formation of more homogeneous wood with more stable mechanical properties [10]. In the case of beech, where wood quality is a key determinant of suitability for industrial and structural uses, these effects assume particular importance.



From a mechanical perspective, wood density is considered one of the key indicators closely related to strength and stiffness. Changes in density caused by silvicultural factors can directly influence the structural performance of wood material [11]. This becomes even more important in the context of the growing demand for structural uses of beech wood and under the influence of climate change, where forest management must be optimized to ensure a sustainable supply of high-quality wood [12].

Although thinning has been widely applied in forestry practice, gaps remain in the literature regarding its specific effects on the physical–mechanical properties of beech wood, particularly under the local conditions of mountainous regions in Southeastern Europe. Thinning intensity, stand age, and ecological conditions can substantially influence outcomes, making further analysis at local and regional scales necessary [13].

In this context, this study aims to investigate the effects of forest thinning at different intensities on the main physical–mechanical parameters of beech wood, by analyzing density, bending strength and compression strength parallel to the grain. The expected results will contribute to improving silvicultural practices and increasing the value of beech wood products, while harmonizing the ecological and economic objectives of forest management.

Materials and Methods

The study was conducted in natural beech forests in three representative regions of Albania: Fushë-Arrëz in the north, (Fushe-Studen) Librazhd in the central region, and Gërmenj-Shelegur (Ersekë) in the south. The selection of these regions aimed to capture the ecological and climatic variability of the main areas where beech forests occur in the country.

Based on forest management plans for each site, two forest stands with similar ecological conditions were selected: one stand without silvicultural interventions (control plot) and one stand where thinning operations had been applied. Within each stand, three experimental plots of 1,000 m² each were established. In total, the study included 18 experimental plots (3 regions × 2 treatments × 3 replicates).

Geospatial technology was used to determine the geographic position and map the experimental plots. A GPS was employed to navigate to the forest stands and record the coordinates of the plot centers. The coordinates collected in the field were imported into a GIS environment to illustrate the spatial distribution of the plots.

For each experimental plot, one representative model tree was selected based on the mean diameter of the stand and the dominant crown condition. From each model tree, cross-sectional discs were taken every 2 m along the stem to analyze annual growth.

For the analysis of physical and mechanical properties, three short logs of 1 m length were taken from each tree: at the base, the middle, and the upper part of the stem. The logs were transported to the Faculty of Forest Sciences in Tirana, where they were sawn into boards with a thickness of 60 mm and air-dried for more than six months. After drying, the mean equilibrium moisture content (EMC) was 11.35% (SD = 1.51), measured according to ISO 13061-1 [14].

Laboratory test specimens were prepared from the dried boards in accordance with SSH ISO 3129:2012 [15]. Before testing, the specimens were conditioned to reach a standard moisture content of 12%. Samples were prepared for the following tests: static bending (MOR) (20×20×320 mm), density (40×40×40 mm), and compression parallel to the grain (20×20×40 mm).

The minimum number of specimens for each test series was determined according to SSH ISO 3129:2012, based on the coefficient of variation (CV), Student’s *t* index, and an error level of $p \leq 5\%$.

Mechanical tests were performed using a universal testing machine “CONTROLAB” (France), with a maximum load capacity of 160 kN. Static bending tests were carried out according to ISO 13061-3:2014 [16], and compression parallel to the grain according to ISO 13061-17:2014 [17]. The data were statistically analyzed using ANOVA to identify significant differences between control and thinned plots. Post-hoc comparisons were conducted at a significance level of $p < 0.05$.

Results and Discussions

Table I presents the results of the annual growth of trees from the three study areas.

Table I: Mean annual ring width [mm]

Location Treatment	Fushë-Studen	Fushë-Arrëz	Gërmenj-Shelegur
Un thinned	1.81	1.47	1.34
Thinned	2.91	3.25	3.30



The results reveal clear differences between unthinned and thinned plots across all geographic areas included in the study. In the unthinned plots, the analyzed parameters showed relatively low values with moderate variation among regions, ranging from 1.34 in Gërmenj–Shelegur to 1.81 in the Fushë–Studen area, with a national average of 1.54. In contrast, the thinned plots exhibited markedly higher values in all regions, ranging from 2.91 mm in Fushë–Studen to 3.30 mm in Gërmenj–Shelegur, with an average increase to 3.15 mm.

This substantial increase in the thinned plots indicates that silvicultural interventions had a direct and positive effect on annual tree ring width, reflecting an improved growth response following the reduction of inter-tree competition for resources such as light, water, and nutrients. Similar responses to thinning have been widely reported in the literature for European beech and other broadleaf species [5,6,10].

The differences observed among geographic regions further suggest that the effect of thinning is not uniform but is influenced by local ecological and climatic conditions, including site fertility, altitude, and moisture availability [8,13]. Nevertheless, the consistent trend across all study areas confirms the importance of thinning as an effective forest management tool for optimizing stand structure, enhancing growth dynamics, and improving the overall functioning of beech forests. Table II presents the results of the mean wood density of trees from the three study areas.

Table II: Mean wood density [gr/cm³] among sites

Treatment \ Location	Fushë-Studen	Fushë-Arrëz	Gërmenj-Shelegur
Un thinned	0.72	0.72	0.73
Thinned	0.64	0.61	0.65

The results presented in the table indicate that unthinned plots exhibit higher wood density values compared to thinned plots across all geographic regions included in the study. Density values in the unthinned plots are relatively homogeneous (0.72÷0.73), whereas the thinned plots showed lower values (0.61÷0.65).

The analysis of variance (ANOVA) further demonstrated that the site factor had a highly significant effect on the wood density of beech. As shown in Table III, differences among the study sites were statistically significant ($F = 126.5, p < 0.001$), confirming that wood density varies markedly depending on local climatic conditions, site characteristics, and forest management practices. These factors directly influence wood formation processes and ultimately determine the final density of beech wood.

Table III: Analysis of variance for density values

Source	Degree of Freedom	Adj SS	Adj MS	F-Value	p -Value
Sites	5	0.589	0.118	126.5	0.00
Error	264	0.246	0.001		
Total	269	0.835			

In particular, silvicultural thinning interventions may play a key role in explaining this variation. Thinning affects the rate of diametric growth of trees by reducing competition for essential resources such as light and water, which is often accompanied by changes in annual ring width and in the proportion of earlywood to latewood. Accelerated growth following intensive thinning can lead to the formation of wood with lower density, potentially resulting in a reduction in the mechanical quality of the material [7,9]. For beech, wood density is one of the main indicators of technological quality, as it is closely related to bending strength and stiffness [3,11]. Consequently, the differences observed among study sites suggest that forest management practices and local ecological conditions must be regarded as decisive factors in the production of high-quality beech wood and its sustainable industrial utilization. Table IV presents the results of the static bending strength (MOR) of trees from the three study areas.

Table IV: Static bending strength (MOR) [N/mm²] among sites

Treatment \ Location	Fushë-Studen	Fushë-Arrëz	Gërmenj-Shelegur
Un thinned	130.63	122.41	139.35
Thinned	126.7	119.46	131.81

The results presented in the table show that unthinned plots exhibit higher values than thinned plots across all geographic regions included in the study. The differences are evident in each area, suggesting that



forest thinning is associated with a slight reduction in static bending strength, with moderate variation depending on local site conditions.

Table V: Analysis of variance for MOR values by study area

Difference of Levels	Difference of Means	SE of Difference	95% of CI		T-Value	Adjusted p -Value
			Min	Max		
FA*-Thin / FA-Unthin	-2.95	4.23	-11.25	5.35	-0.7	0.49
FS**-No Thin / FA-Unthin	8.22	4.01	0.34	16.1	2.05	0.04
FS-Thin / FA-Unthin	4.29	4.43	-4.41	12.99	0.97	0.33
GER****-Unthin/ FA-Unthin	16.94	3.76	9.56	24.32	4.51	0.00
GER-Thin / FA-Unthin	9.40	3.91	1.72	17.08	2.4	0.02
FS-Unthin/ FA-Thin	11.17	4.19	2.94	19.4	2.66	0.01
FS-Thin / FA-Thin	7.24	4.6	-1.78	16.26	1.58	0.12

* FA - Fushë-Arrëz; **FS – Fushë-Studen; ***GER – Gërmenj-Shelegur

The results of the analysis of variance (Table V) indicate that the static bending strength of beech wood varies significantly among certain locations, reflecting the influence of site conditions and silvicultural practices on the development of wood mechanical properties. The statistically significant differences observed between unthinned plots in Gërmenj–Shelegur and those in Fushë–Arrëz suggest that sites with more favorable ecological potential produce wood with higher static bending strength.

In contrast, the absence of significant differences between thinned and unthinned plots within the same location indicates that forest thinning primarily affects stem diametric growth without substantially reducing the static bending strength of the wood. This finding suggests that, when thinning is applied in a controlled manner, it can increase volume production and tree diameter while simultaneously maintaining the mechanical performance of wood material. From a practical forest management perspective, these results highlight that thinning strategies should be adapted to local site conditions in order to balance growth objectives with mechanical wood quality. Such an approach can ensure a reliable supply of beech wood suitable for high-value structural and industrial applications.

Table VI: Analysis of variance for MOR values at national level

Source	Degree of Freedom	Adj SS	Adj MS	F-Value	p-Value
Sites	5	32746	6549.3	6.9	0
Error	704	668055	948.9		
Total	709	700801			

The results of the analysis of variance (Table VI) at the national level indicate that the site factor has a highly significant statistical effect on MOR values of beech wood. As shown in the table VI, differences among locations were statistically significant ($F = 6.9, p < 0.001$), confirming that spatial variation explains a substantial portion of the total variation in static bending strength. The ratio between the mean square for sites ($Adj MS = 6549.3$) and the error mean square ($Adj MS = 948.9$) further indicates that differences among locations are markedly greater than within-site variation, emphasizing the importance of site-related factors in the development of wood mechanical properties.

These results suggest that site conditions and silvicultural interventions, including forest thinning, directly influence the formation of the anatomical structure and mechanical properties of beech wood. It is well established in the literature that static bending strength is closely related to wood density, annual ring width, and the proportion of earlywood to latewood [3,11]. By reducing competition for light and water, thinning promotes faster diametric growth, which is often associated with wider growth rings and slightly lower wood density, potentially leading to a moderate reduction in mechanical strength [7,10].

The differences observed among locations indicate that the effects of thinning are not uniform but interact with local factors such as climate, soil type, elevation, and forest management history. Other studies on beech have shown that sites with more favorable ecological conditions tend to produce wood with higher MOR values, regardless of thinning intensity, highlighting the dominant role of environmental factors alongside silvicultural practices [8,13].



From a practical forest management perspective, these findings underscore the need for specific thinning strategies referring to region and site, in order to balance volume growth and stem diameter with the preservation of static bending strength. Such an approach is essential to ensure the production of high quality beech wood suitable for high value structural and industrial applications, while harmonizing production objectives with the long-term sustainability of forest ecosystems. Table VII presents the results of compression strength parallel to the grain for trees from the three study areas.

Table VII: Compression strength parallel to the grain [N/mm²]

Location Treatment	Fushë-Studen	Fushë-Arrëz	Gërmenj-Shelegur
Un thinned	61.38	60.47	58.01
Thinned	57.44	54.16	53.61

The results presented in the table show that the compression strength parallel to the grain of beech wood is higher in unthinned plots compared to thinned plots across all geographic regions included in the study. The highest values were observed in the Fushë–Studen area (61.38) and the lowest in Gërmenj–Shelegur (58.01) for unthinned plots, whereas after thinning the compression strength decreased to a range of 53.61 ÷ 57.44.

This trend suggests that forest thinning, by promoting faster diameter growth, may lead to a slight reduction in compression strength parallel to the grain. Nevertheless, the variation observed among regions indicates that local site conditions also play an important role in shaping the mechanical properties of beech wood.

Table VIII: Analysis of variance for compression strength parallel to the grain values at national level

Source	Degree of Freedom	Adj SS	Adj MS	F-Value	p -Value
Sites	5	6762	1352.5	2.5	0.03
Error	825	446660	541.4		
Total	830	453423			

The results of the analysis of variance (Table VIII) indicate that the site factor has a statistically significant effect on the compression strength parallel to the grain of beech wood ($F = 2.5, p = 0.03$). This finding demonstrates that spatial differences among the study sites contribute significantly to the variation of this mechanical property, although the effect is less pronounced compared to other mechanical parameters such as bending strength.

Compression strength parallel to the grain is closely related to wood density and anatomical structure, particularly the orientation and thickness of cell walls [3,11]. The differences observed among locations suggest that site conditions and silvicultural practices, including forest thinning, influence growth rates and wood tissue formation, thereby resulting in moderate variations in compression strength. Thinning, by promoting faster diametric growth, may lead to the formation of wood with slightly lower density, which is often associated with a slight reduction in compression strength parallel to the grain [7,10].

From a forest management perspective, these results indicate that thinning strategies should balance growth and volume production objectives with the preservation of wood mechanical properties, particularly when beech wood is intended for structural or industrial applications where compression strength is a key functional parameter.

Conclusions

The results of this study clearly confirm that silvicultural thinning represents a decisive factor in regulating the growth, structure, and technological properties of beech wood, while its effects strongly interact with local ecological and site conditions. Thinned plots exhibited significantly higher annual and diametric growth compared to unthinned plots, demonstrating that the reduction of competition for resources promotes sustainable forest productivity. This positive response was observed across all geographic areas, although with varying intensity, indicating that thinning does not have a uniform effect but is influenced by local factors such as climate, soil characteristics, and ecological potential.

On the other hand, the analyses show that unthinned plots are characterized by higher wood density and slightly higher mechanical properties, such as static bending strength and compression strength parallel to the grain. Thinning is associated with a moderate reduction in these parameters, linked to faster growth rates and the formation of wood with slightly lower density. However, statistical results indicate that within the same site,



differences between thinned and unthinned plots are not always significant, particularly for bending strength, suggesting that properly applied thinning does not substantially compromise the mechanical quality of the wood.

ANOVA results at both local and national levels confirm that the site factor has a highly significant influence on wood density and mechanical properties, highlighting the key role of site conditions and management history. In conclusion, the study demonstrates that thinning strategies should be adapted to regional conditions and management objectives in order to achieve an optimal balance between volume growth, stem diameter, and the preservation of mechanical quality, thereby ensuring sustainable production and high-value industrial use of beech wood.

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