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Article

MECHANICAL AND HYGROSCOPIC PROPERTIES OF CHESTNUT WOOD (CASTANEA SATIVA MILL.) FROM MOUNT ATHOS

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ABSTRACT

Chestnut wood (Castanea sativa Mill.) from Mount Athos remains insufficiently studied compared to other Mediterranean provenances of the species. In this study, basic mechanical properties (bending strength, compressive strength, impact strength, and hardness) and hygroscopic properties (water absorption and linear swelling) were determined on wood samples collected during 2018, 2019, and 2020, in accordance with the relevant ISO standards. Statistical processing of the results was performed using one-way analysis of variance (ANOVA) to investigate potential differences between collection years. Wood density remained statistically stable over the three-year period (approximately 0.62–0.63 g/cm³), while bending strength and modulus of elasticity showed no statistically significant differences. Conversely, compressive strength, impact strength, and Janka hardness showed statistically significant differences between years ($p < 0.001$), with a downward trend from 2018 to 2020. Regarding hygroscopic properties, statistically significant differences between years were observed mainly after 48 h of immersion, but not after 24 h. The results were compared with corresponding values in the international literature and found to fall within comparable ranges; they provide primary reference data for this specific Greek population.

Keywords: *Wood; Castanea sativa; chestnut; Mount Athos; mechanical properties; hygroscopic properties*

1 INTRODUCTION

Chestnut wood (Castanea sativa Mill.) is among the most important native species of the Mediterranean, with wide use in structural, construction, and traditional applications, owing to the combination of satisfactory mechanical strength and natural durability [1]. Evaluating its suitability for such uses requires the systematic determination of mechanical properties—bending strength, impact, compression, and hardness—and hygroscopic properties, especially water absorption and swelling, as the interaction of these two properties ultimately determines the dimensional stability and long-term mechanical performance of the material under real conditions of use.

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The bending and compressive strength of chestnut wood have been determined in various European countries, both with traditional static methods and with non-destructive techniques, such as ultrasonic wave propagation [2] and visual grading of structural timber combined with estimated modulus of elasticity [3]. Hardness and impact strength, although less frequently studied than bending and compression, are equally critical parameters for evaluating wood resistance to mechanical stress, especially in flooring applications and high-stress applications.

Geographical origin also appears to significantly influence the mechanical properties of chestnut, as shown by Romagnoli and Spina [4], who found statistically significant differences in strength and shrinkage between samples from different locations within the same geographical area, demonstrating the need for documentation at the level of a specific population rather than only at the species level.

The hygroscopic properties of chestnut wood, especially water absorption and subsequent swelling, are closely linked to its chemical composition. Militz et al. [1] found that the low water vapor permeability of chestnut wood, compared to coniferous species such as Pinus radiata, is attributable to wood extractives, which limit the available void space in the cell wall and consequently the water uptake capacity. This relationship between moisture uptake and mechanical behavior is further supported by aging studies, where it was found that, despite long-term outdoor exposure, the water absorption capacity and mechanical properties of aged chestnut wood remained comparable to those of younger wood [5], indicating relative stability of the species' hygroscopic properties over time.

Despite these findings, the vast majority of available data on the mechanical and hygroscopic properties of chestnut originate from populations in Italy, Spain, and other Western Mediterranean countries, while Greek provenances remain insufficiently studied. The chestnut population of Mount Athos is of particular interest, as it has developed under specific edaphoclimatic conditions and long-term traditional management by the Holy Monasteries—factors that may have influenced both the mechanical and hygroscopic properties of the wood, although this has not previously been confirmed through systematic measurements.

In this context, the purpose of this study is to determine basic mechanical properties (bending strength, impact, compression, and hardness) and hygroscopic characteristics (water absorption and swelling) of chestnut wood originating from Mount Athos, based on samples collected during 2018, 2019, and 2020, with the aim of producing primary reference data for this population and contributing to the international literature on the relationship between the mechanical and hygroscopic properties of the species.

2 MATERIALS AND METHODS

Chestnut wood (Castanea sativa Mill.) used in this study was collected during 2018, 2019, and 2020. Boards were cut parallel to the grain and placed in a conditioned room at 20 ± 2 °C and 60 ± 5% relative humidity, where they remained until reaching a nominal equilibrium moisture content (EMC) of 8.3%. The average density (dry mass/volume, measured at 8.3% moisture content) of the wood was found to be 0.623 g/cm³.

Boards were cut to final cross-sectional dimensions for the measurement of mechanical properties, according to the respective standards (bending strength–modulus of elasticity: ISO 3133:1975; compression parallel to grain: ISO 3787:1976; impact: ISO 3348:1975; hardness (Janka): ISO 3350:1975). For each property test, 15 replicate specimens were prepared. Specimens were weighed before testing, oven-dried at 103 ± 2 °C for 24 h, and reweighed to estimate the average moisture content of the specimens during testing.

Figure 1. Chestnut wood specimens with collection-date code marking (a) and detail of their cross-section (b), prior to cutting to final test dimensions.

Bending, compression, and hardness tests were performed on a SHIMADZU UH-300kNA universal testing machine. In the bending tests, the crosshead movement rate was set at 6 mm/min, so that the maximum load was reached within 1.5 ± 0.5 min throughout the test. Loading continued until specimen failure. Impact tests were performed on a WPM Leipzig PSd 150H pendulum impact testing machine, Charpy type.

Figure 2. Sequence of mechanical tests on chestnut wood specimens: (a) three-point bending test and (b) compression test parallel to grain, both on the SHIMADZU UH-300kNA machine; (c) impact test on the WPM Leipzig PSd 150H pendulum impact machine.

To evaluate hygroscopic properties, specimens were fully immersed in water at 20 ± 3°C for intervals of 24 and 48 h.

Figure 3. Chestnut wood specimens during immersion in water, as part of the water absorption and swelling test.

After each immersion interval, specimen dimensions were measured with a precision caliper to determine linear swelling according to ISO 4859:1982, and specimen weight was measured with an analytical balance to calculate the water absorption percentage.

Statistical analysis was performed using SPSS software, applying one-way ANOVA to evaluate statistically significant differences in mechanical and hygroscopic properties between collection years (2018, 2019, 2020).

3 RESULTS AND DISCUSSION

3.1 Wood density

Average chestnut wood density ranged from 0.627 g/cm³ (2018) to 0.623 g/cm³ (2020), with minimal variation between collection years (0.627, 0.626, and 0.623 g/cm³ for 2018, 2019, and 2020, respectively). ANOVA showed no statistically significant difference ($F = 0.065$, $p =$

0.938), indicating that density remained essentially stable in the Mount Athos population throughout the three-year sampling period. These values fall within the range reported for chestnut of Italian origin (0.557–0.641 g/cm^3 in Amiata region forests) [6].

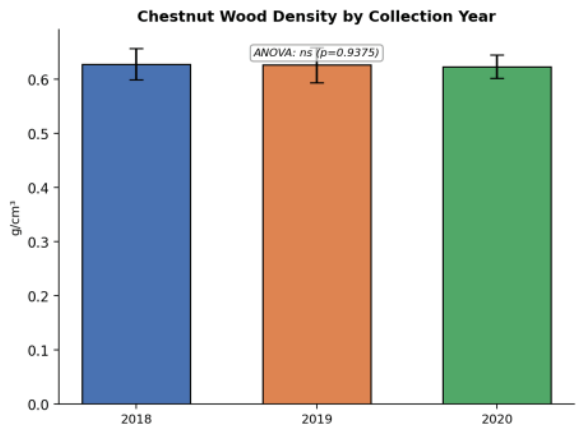

Figure 4. Chestnut wood density by collection year (mean value ± standard deviation).

3.2 Mechanical properties

Table 1. Summary results of chestnut wood mechanical properties by collection year (mean value ± standard deviation) and one-way ANOVA results.

Property	2018	2019	2020	F	p
MOR, N/mm^2	100.2 ± 12.6	108.8 ± 17.1	99.0 ± 18.2	1.03	0.372
MOE, N/mm^2	11054 ± 813	10373 ± 1206	9537 ± 1826	3.18	0.058
Compression, N/mm^2	65.4 ± 2.7	56.8 ± 4.6	53.1 ± 2.8	15.65	<0.001
Impact, J/mm^2	5.50 ± 0.97	8.56 ± 2.04	5.78 ± 1.14	11.48	<0.001
Hardness tang., N/mm^2	3.19 ± 0.15	3.09 ± 0.09	2.53 ± 0.37	13.83	<0.001
Hardness rad., N/mm^2	3.24 ± 0.32	2.85 ± 0.17	2.25 ± 0.10	36.49	<0.001

Bending strength (MOR) ranged from 99.0 N/mm^2 (2020) to 108.8 N/mm^2 (2019), with no statistically significant difference between years ($F = 1.03$, $p = 0.372$). A similar pattern was observed for the modulus of elasticity (MOE), which showed a downward trend from 11054 N/mm^2 (2018) to 9537 N/mm^2 (2020), although the difference was not statistically significant at the 0.05 level ($F = 3.18$, $p = 0.058$), with the p-value marginally close to the significance threshold. These values are comparable to the findings of Thaler et al. [5], who reported MOR of 94.5–113.5 N/mm^2 and MOE of 6709–9379 N/mm^2 for recent and old chestnut wood, respectively, as well as with subsequent studies on sawn chestnut where the average MOE from bending tests was approximately 11100 N/mm^2 [7].

In contrast, compressive strength parallel to the grain showed a statistically significant decrease from 2018 (65.4 N/mm²) to 2020 (53.1 N/mm²) ($F = 15.65$, $p < 0.001$). These values are comparable to corresponding measurements for Italian chestnut origins (47–54 MPa in Amiata forests) [6], with the 2018 values at the upper end of this range. Impact strength showed a statistically significant difference between years ($F = 11.48$, $p < 0.001$), with 2019 standing out with a distinctly higher value (8.56 J/mm²) than 2018 (5.50 J/mm²) and 2020 (5.78 J/mm²), without a clear monotonic trend over time. Finally, Janka hardness, in both the tangential ($F = 13.83$, $p < 0.001$) and radial ($F = 36.49$, $p < 0.001$) directions, showed a statistically significant and consistently decreasing trend from 2018 to 2020, with values decreasing by approximately 21% (tangential) and 30% (radial) relative to 2018.

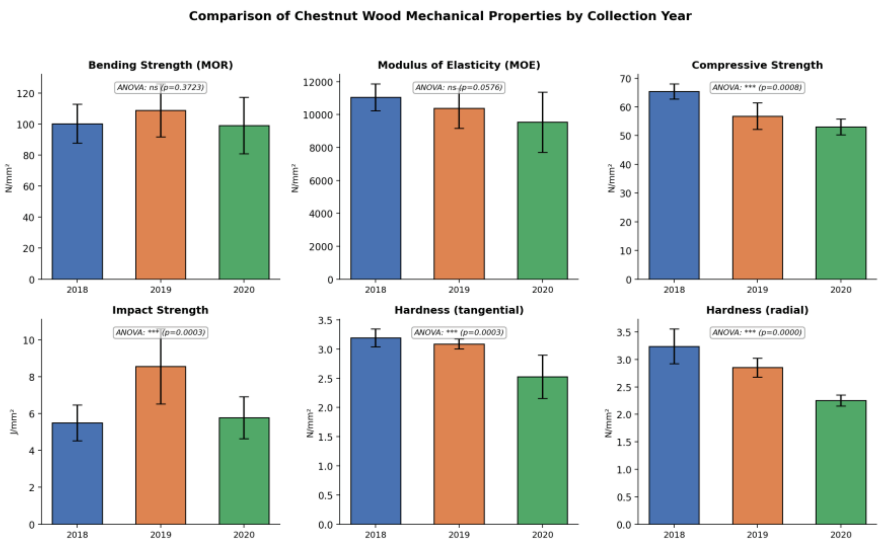

Figure 5. Comparison of chestnut wood mechanical properties by collection year (mean ± standard deviation). ANOVA significance: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ns = not statistically significant.

3.3 Hygroscopic properties

Table 2. Summary results of chestnut wood hygroscopic properties by collection year (mean value ± standard deviation) and one-way ANOVA results.

Property	2018	2019	2020	F	p
Density, g/cm³	0.627 ± 0.029	0.626 ± 0.033	0.623 ± 0.022	0.07	0.938
Water absorption 24 h, %	10.84 ± 0.88	11.44 ± 0.71	10.64 ± 0.81	2.70	0.085
Water absorption 48 h, %	4.78 ± 0.36	4.73 ± 0.26	4.39 ± 0.35	4.41	0.022
Swelling length 24 h, %	0.05 ± 0.04	0.06 ± 0.05	0.20 ± 0.26	2.88	0.073
Swelling length 48 h, %	0.10 ± 0.06	0.03 ± 0.03	0.02 ± 0.03	11.74	<0.001

Property	2018	2019	2020	F	p
Swelling thickness 24 h, %	1.74 ± 1.15	1.81 ± 0.79	1.83 ± 1.20	0.02	0.984
Swelling thickness 48 h, %	0.88 ± 0.76	0.60 ± 0.27	0.44 ± 0.40	1.80	0.186
Swelling width 24 h, %	1.99 ± 0.99	1.85 ± 0.47	2.20 ± 0.78	0.54	0.590
Swelling width 48 h, %	1.44 ± 0.92	0.31 ± 0.22	0.57 ± 0.43	9.54	<0.001

Water absorption after 24 h of immersion ranged from 10.6% (2020) to 11.4% (2019), with no statistically significant difference between years ($F = 2.70$, $p = 0.085$), while after 48 h the difference became statistically significant ($F = 4.41$, $p = 0.022$), with 2020 showing the lowest value (4.39%) compared with 2018 (4.78%) and 2019 (4.73%).

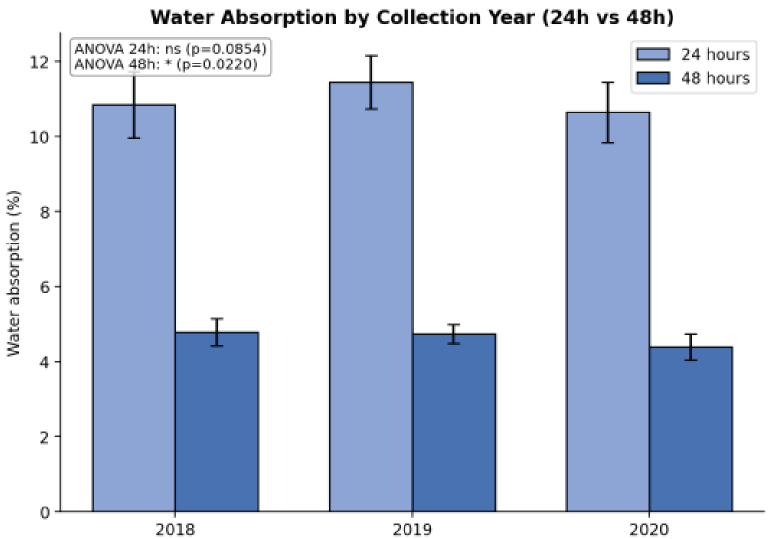

Figure 6. Water absorption of chestnut wood by collection year, after 24 and 48 h of immersion.

Linear swelling in thickness and width at 24 h showed no statistically significant difference between years ($F = 0.02$, $p = 0.984$ and $F = 0.54$, $p = 0.590$, respectively), while swelling in length at 24 h was marginally non-significant ($F = 2.88$, $p = 0.073$), with 2020 showing a noticeably higher mean value (0.20%) than 2018 and 2019 (approximately 0.05–0.06%), albeit with high dispersion. At 48 h, swelling in length ($F = 11.74$, $p < 0.001$) and width ($F = 9.54$, $p < 0.001$) showed statistically significant differences, with 2018 consistently exhibiting higher swelling values than 2019 and 2020. Thickness swelling at 48 h was not statistically significant ($F = 1.80$, $p = 0.186$), although a downward trend was observed from 2018 (0.88%) to 2020 (0.44%).

In all cases, the linear swelling values recorded in the present experiment (24–48 h of partial immersion, range approximately 0.02–2.2%) are clearly lower than the maximum swelling/shrinkage values at full saturation reported for Greek chestnut (maximum radial shrinkage ≈3.83% and tangential ≈6.58%) [8], which is expected given that the present measurements correspond to early stages of moisture uptake rather than full saturation of the cell walls.

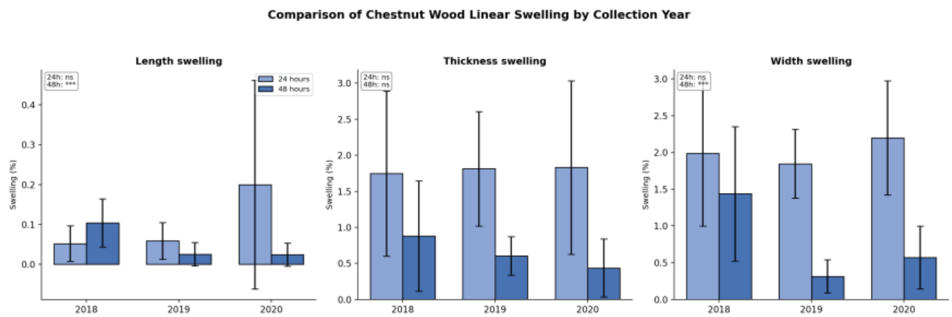

Figure 7. Comparison of linear swelling (length, thickness, and width) of chestnut wood by collection year, after 24 and 48 h of immersion.

3.4 Summary discussion

Overall, the mechanical properties most closely related to wood density and structural integrity (compression, impact, hardness) showed statistically significant differences between collection years, while bending properties (MOR, MOE) remained statistically stable. The downward trend in hardness and compressive strength from 2018 to 2020, despite stable density, could be linked to variation in chemical composition or growth conditions of the samples among collection years—a finding consistent with Romagnoli and Spina [4] regarding the importance of specific origin and sampling location for the mechanical properties of chestnut, beyond the species level. Similarly, for hygroscopic properties, differences between years became apparent mainly at 48 h of immersion, indicating that year-to-year variation in wood composition or structure affects long-term moisture uptake more than short-term uptake.

4 CONCLUSIONS

The density of chestnut wood from Mount Athos remained statistically unchanged between collection years (2018–2020), making it unlikely that density is the determining factor behind the differences observed in individual mechanical and hygroscopic properties. This indicates that annual variability is more likely related to the chemical composition of the wood (e.g., extractive content) or microstructural characteristics (e.g., growth-ring width) rather than to simple changes in apparent density.

Mechanical properties did not respond uniformly to the collection-year factor: bending strength and modulus of elasticity—properties that depend heavily on the overall structural behavior of the specimen—remained statistically stable, while compression, impact, and hardness, properties more sensitive to local changes in cellular structure and chemical composition, showed statistically significant differences. The declining trend in hardness and compression from 2018 to 2020 is the most consistent finding of this study and would merit further investigation regarding its relationship to factors such as wood age at collection or the prevailing climatic conditions of each year.

In hygroscopic properties, the absence of significant differences at 24 h of immersion, combined with the emergence of statistically significant differences at 48 h (in both water absorption and linear swelling in length and width), indicates that inter-annual variation becomes apparent only after prolonged moisture exposure—a possible indication that slower diffusion mechanisms, linked to wood chemical composition rather than initial porous structure alone, are involved. In any case, the absolute swelling values recorded remain clearly lower than the maximum full-saturation values reported for Greek chestnut, consistent with the relatively short immersion duration (24–48 h) used in this study.

Overall, the density, bending strength, and compressive-strength values recorded for Mount Athos chestnut fall within the range reported for other Mediterranean origins of the species (Italy, Spain), partially filling the data gap for Greek provenances identified in the international literature. At the same time, the statistically documented annual variability in several properties highlights the need for wood-property documentation that accounts for the long-term variability of a given population, rather than relying on isolated measurements—particularly where the wood is intended for structural or other demanding applications.

ABBREVIATIONS

The following abbreviations are used in this manuscript: MOR, modulus of rupture (bending strength); MOE, modulus of elasticity; EMC, equilibrium moisture content; ANOVA, analysis of variance; ISO, International Organization for Standardization; SPSS, Statistical Package for the Social Sciences.

AUTHOR CONTRIBUTIONS

Conceptualization, A.M. and D.K.; methodology, A.M. and K.N.; software, D.K.; validation, A.M., K.N. and G.N.; formal analysis, D.K.; investigation, A.M., K.T. and P.N.; resources, G.N.; data curation, K.N.; writing—original draft preparation, A.M.; writing—review

and editing, A.M. and D.K.; visualization, D.K.; supervision, G.N.; project administration, A.M. All authors have read and agreed to the published version of the manuscript.

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During the preparation of this manuscript, the authors used Claude (Anthropic) for the generation of data visualization charts. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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