

Experimental Study on the Identification and Mechanical Characterization of Local Bamboo from Benin for Its Use in Wood-Concrete Composite Structures

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How to cite this paper: Dara, S.K., Peace, H.S., Djoui, T., Doko, K.V. and Gibigaye, M. (2025) Experimental Study on the Identification and Mechanical Characterization of Local Bamboo from Benin for Its Use in Wood-Concrete Composite Structures. *World Journal of Engineering and Technology*, 13, 923-933.
<https://doi.org/10.4236/wjet.2025.134057>

Received: August 31, 2025

Accepted: November 8, 2025

Published: November 11, 2025

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Abstract

This study investigates the mechanical potential of local bamboo species from southern Benin, particularly *Bambusa vulgaris*, for use in hybrid timber-concrete structures. While bamboo has gained recognition as a sustainable and high-performance bio-based material, the mechanical properties of African species remain underexplored. A comprehensive experimental campaign was conducted involving three-point and four-point bending tests on parallelepiped specimens machined from bamboo stems. Key mechanical parameters—maximum force, displacement at failure, apparent modulus of elasticity, and specific fracture energy—were measured and analyzed. Results revealed significant variability across different specimen configurations, with some values comparable to or exceeding those of common tropical hardwoods. The findings confirm the structural relevance of local bamboo as a sustainable alternative in composite floor systems. Future work will focus on tensile and compressive behavior, long-term performance, and interface mechanics with concrete.

Keywords

Local Bamboo, *Bambusa Vulgaris*, Timber-Concrete Composite, Bending Test, Tropical Materials, Bio-Based Construction, Flexural Performance, Adsorption

1. Introduction

In a global context of ecological transition, reducing the carbon footprint of construction materials is a top priority for the building and public works sector. Bio-based materials, such as wood, flax, hemp, or bamboo, are experiencing renewed interest due to their renewable nature, low energy cost of processing, and contribution to the circular economy [1]. Bamboo, in particular, stands out for its rapid growth, high availability in tropical areas, and remarkable mechanical properties. It is a strategic resource for sustainable construction in the Global South, especially in sub-Saharan Africa.

However, bamboo species found in West Africa, such as *Bambusa vulgaris*, remain little studied scientifically, unlike better-documented Asian species. This gap currently limits their use in innovative construction systems, despite their obvious potential.

Wood-concrete composite structures are currently an effective technical solution for combining lightness, mechanical strength, and environmental performance. The wood-concrete interface, ensured by various types of connectors, allows for balanced distribution of forces and increased overall rigidity [1] [2]. In this context, integrating bamboo as a substitute for conventional wood represents a promising opportunity, particularly in tropical areas where this resource is abundant and underutilized [3].

However, despite growing interest in bamboo as a sustainable construction material, most existing research concerns Asian species (*Phyllostachys edulis*, *Dendrocalamus asper*, etc.) within Asian or European normative contexts. Local species such as *Bambusa vulgaris*, which is widespread in West Africa and especially in Benin, remain poorly characterized in terms of mechanical and physical properties [2]. This scientific gap hinders their integration into hybrid wood-concrete systems due to a lack of reliable experimental data and protocols adapted to their morphological and environmental specificities [4] [5]. Furthermore, international design standards [6] only marginally incorporate the particularities of tropical materials and are difficult to apply without methodological adjustments. Therefore, a better understanding of the properties of African bamboos, obtained through rigorous experimental testing, is essential for their use in low environmental impact composite structures.

The lack of standardized data on local bamboos from Benin limits their use in wood-concrete composite structures, despite their clear potential in terms of lightness, tensile strength, and natural durability. A campaign of identification and mechanical characterization is therefore essential to assess their suitability for structural use. This involves not only determining their physical properties (density, porosity, moisture content) but also their mechanical behavior in bending, tension, and compression, in accordance with applicable normative requirements.

The present study aims to identify and mechanically characterize a local bamboo species collected in the southern regions of Benin, in order to assess its potential for integration into wood-concrete composite structures. The main objec-

tive is to produce reliable experimental data on the morphology, physical properties, and mechanical performance of this natural material. The experimental approach is initially based on bending tests (three- and four-point), and will later be extended to tension and compression tests, in order to establish a comprehensive database for structural modeling.

The study is part of a dynamic of technological innovation, valorization of local resources, and transition towards low environmental impact construction, adapted to the tropical contexts of sub-Saharan Africa.

2. Methodology

2.1. Materials and Tested Specimens

The material used in this study is local bamboo, widely distributed across the southern regions of Benin. The species utilized was visually identified as belonging to the *Bambusa vulgaris* genus, based on standard botanical criteria commonly used in West Africa [7]. This identification relied on morphological observations conducted as part of an internal, unpublished study on bamboo populations in the Ouémé and Plateau departments. Further taxonomic analysis is currently underway for future scientific publication.

The basic physical properties of the raw bamboo were preliminarily assessed. The apparent density ranged from 407 to 719 kg/m³, while the natural moisture content varied between 19% and 63%, depending on the sampling location and initial storage conditions. These value ranges are consistent with those reported in the literature for tropical bamboo species [8], thus confirming the structural relevance of the material for the intended applications in this study.

For the mechanical testing phase, rectangular parallelepiped specimens were carefully machined using both manual and semi-automated tools. The adopted geometry for flexural testing was 200 mm × 50 mm × 20 mm, in accordance with the specifications of the European standard EN 310 (French version), which governs bending tests on wood-based panels. All dimensions were verified using a digital caliper with ±0.1 mm precision, measured at three longitudinal points on each surface to ensure geometric uniformity. Any specimen exhibiting visible defects (e.g., open nodes, cracks, mold) was discarded.

The choice of these dimensions is justified by EN 310 recommendations, which require the specimen length to be at least 20 times its thickness. For a 20 mm thickness, a minimum length of 400 mm would typically be required. However, given the exploratory nature of this study conducted at a semi-reduced scale, dimensional adaptations were made to accommodate fabrication constraints and the modular configuration of the testing rig, while maintaining geometric similarity and representative behavior. A width of 50 mm was selected to ensure sufficient lateral stability while remaining within the standard's recommended range.

Particular attention was paid to ensuring dimensional consistency, eliminating visible defects (e.g., nodes, splits, fungal spots), and labeling each specimen for full traceability throughout the experimental campaign.

Representative photographic views of the selected bamboo stems and machined specimens are provided in **Figure 1(a)** (raw material overview) and **Figure 1(b)** (specimen geometry and sandwich configuration), respectively.

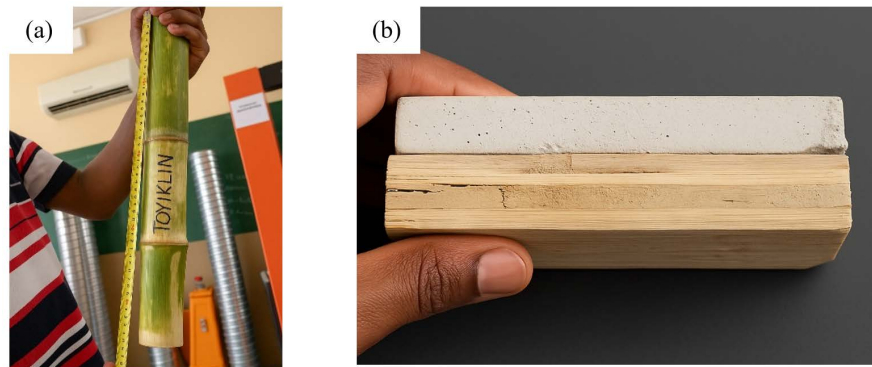


Figure 1. Raw bamboo stem prior to testing (a), Bamboo-wood-concrete sandwich specimen (transverse section showing core configuration) (b).

2.2. Equipment and Testing Protocol

Mechanical tests conducted in this study focused on evaluating the flexural behavior of locally sourced bamboo using two distinct configurations: three-point bending (3PB) and four-point bending (4PB). These tests were performed following a protocol inspired by the European standard EN 310 (French version), adapted to the local experimental setup and the exploratory nature of the research.

2.2.1. Equipment and Instrumentation

The tests were performed using an IGM 3R hydraulic press, equipped with:

- A force-controlled loading system with a readout accuracy of ± 0.5 N.
- A set of cylindrical steel supports with a 5 mm radius, ensuring uniform load distribution without excessive stress concentrations.
- An automated data acquisition system enabling continuous recording of applied force (F) and displacement (δ) throughout the test, with sufficient sampling frequency to capture the linear elastic phase, any plastic deformation, and the failure point.

Prior calibration of the press and displacement indicator was conducted in accordance with the laboratory's internal procedures to ensure measurement reliability.

2.2.2. Specimen Preparation and Test Conditions

Specimens were carefully machined from straight bamboo culm segments, avoiding nodal regions. Each sample was measured using a digital caliper (± 0.1 mm precision), with three measurements per face to control for width (b), thickness (h), and length (L). Any sample showing visible defects (cracks, mold, significant geometric irregularities) was excluded. Specimens were conditioned at constant temperature and humidity ($25^\circ\text{C} - 28^\circ\text{C}$, 70% RH) for 72 hours prior to testing to limit hygroscopic variability.

The span between supports was set to 180 mm, resulting in a span-to-depth ratio of 9, which is below the EN 310 recommended value of 20. This deviation was due to technical constraints related to the test bench configuration and is discussed as a limitation in Section 3.2.

2.2.3. Three-Point Bending (3PB) Protocol

Loading was applied centrally in a monotonic and quasi-static manner, with a crosshead displacement rate of 0.4 mm/s, as prescribed by EN 310. The specimen was simply supported on two fixed bearings, and the loading punch applied a vertical force at midspan.

For each test, the following parameters were recorded:

- Maximum force (F_{max}) [kN];
- Displacement at F_{max} (Δ_{max}) [mm];
- Observed failure mode (tensile failure of outer fibers, localized buckling, longitudinal splitting, etc.);
- Force-displacement curve ($F - \delta$).

2.2.4. Four-Point Bending (4PB) Protocol

In the 4PB configuration, the total support span remained at 180 mm. Two loading points, spaced 60 mm apart, were symmetrically placed to apply force. This setup promotes more uniform stress distribution in the central region and reduces localized stress effects near the loading points (Figure 2).

The same set of parameters was measured as in the 3PB tests, with particular attention paid to post-peak behavior (ductility, progressive cracking).

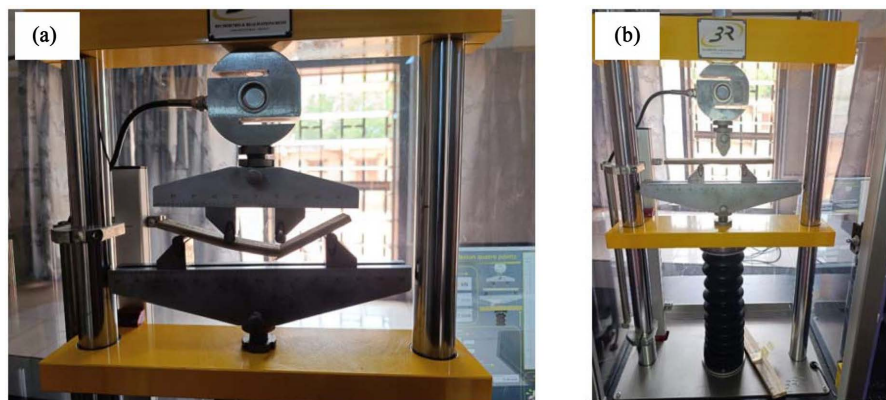


Figure 2. General view of the IGM 3R hydraulic press used for the flexural tests (a), detail of the support system for three- and four-point bending configurations (b).

2.3. Calculation Methods for Mechanical Properties

In this experimental study, bending tests were performed using two distinct configurations: three-point bending (3PB) and four-point bending (4PB) (Figure 3). The analytical formulas used to process the raw data are derived from classical strength of materials theory, assuming linear and isotropic behavior in the initial elastic phase.



Figure 3. Example of four-point bending test setup with local bamboo specimens.

2.3.1. Three-Point Bending

In Equation (1), for a three-point bending test, the maximum bending stress σ_{\max} at the mid-span of the specimen is calculated using the following expression:

$$\sigma_{\max} = \frac{3F(l-a)}{2bd^2} \quad (1)$$

where:

- F is the maximum applied load [N];
- L is the support span [mm];
- b is the width of the specimen [mm];
- d is the thickness (or height) of the specimen [mm].

The maximum deflection δ_{\max} is also recorded for each sample to plot load-displacement ($F-\delta$) curves and identify characteristic behavior phases.

2.3.2. Four-Point Bending

For four-point bending tests, the maximum bending stress is computed using the following Equation (2):

$$\sigma_{\max} = \frac{3F(l-a)}{2bd^2} \quad (2)$$

where:

- F is the maximum load [N];
- l is the total support span [mm];
- a is the distance from the support to the loading point [mm] (symmetrical);
- b and d represent the width and height of the specimen, respectively [mm].

This configuration ensures a more uniform stress distribution in the central region of the specimen and is better suited for characterizing materials sensitive to stress concentrations.

2.3.3. Apparent Modulus of Elasticity (E)

The flexural modulus of elasticity E (Equation (3), Equation (4)) is estimated from the initial slope m of the load-displacement ($F-\delta$) curve in the linear range, using

the following relationships:

- For 3PB:

$$E = \frac{L^3 m}{4bd^3} \quad (3)$$

- For 4PB:

$$E = \frac{(l-a)^3 m}{4bd^3} \quad (4)$$

2.3.4. Specific Fracture Energy

The energy absorbed up to failure is calculated as the area under the load-displacement curve ($F - \delta$), normalized by the specimen volume, to obtain the specific fracture energy (in J/mm^3). This parameter provides additional insight into the toughness and energy dissipation potential of the tested material.

3. Results and Discussion

3.1. Experimental Results

Although the number of specimens per configuration remains limited at this exploratory stage, the results are presented with careful attention to consistency and representativeness. The reported values correspond to the average of valid tests, with indication of variability when relevant.

This experimental study focuses exclusively on three-point bending (3PB) and four-point bending (4PB) tests performed on locally sourced bamboo specimens, machined according to different assembly configurations. This methodological choice stems from the need to first characterize the flexural behavior, which is the predominant loading mode in the targeted structural applications, such as wood-wood-concrete sandwich floor elements. Tensile and compressive tests, although complementary, will be addressed in future investigations.

The mechanical parameters analyzed for each tested specimen type include the maximum load (F_{max}), displacement at failure (Δ_{max}), apparent modulus of elasticity (E), and specific fracture energy (U_s). Data are grouped by assembly type and test configuration.

3.1.1. Summary of Three-Point Bending Results

A total of 21 three-point bending tests were carried out on seven families of specimens. **Table 1** presents the measured values of maximum force (F_{max}), displacement at maximum load (Δ_{max}), apparent modulus of elasticity (E), and estimated specific fracture energy (U_s).

Table 1. Experimental results—three-point bending.

Specimen	F_{max} (kN)	Δ_{max} (mm)	E (MPa)	U_s (J/mm^3)
ADF3-1	2.24	4.84	2500	0.15
ADF3-2	2.20	4.66	2450	0.14

Continued

ADF3-3	1.92	6.07	2300	0.13
COF3-1	4.21	3.45	4100	0.28
COF3-2	4.48	5.59	4300	0.30
COF3-3	5.03	6.26	4600	0.35
KPF3-1	2.60	5.70	3000	0.20

3.1.2. Summary of Four-Point Bending Results

The four-point bending tests were conducted on sandwich-type (wood-wood-concrete) and wood-wood specimens. **Table 2** summarizes the experimental results following the same logic.

Table 2. Experimental results—four-point bending.

Specimen	F_max (kN)	Δ_{max} (mm)	E (MPa)	U_s (J/mm ³)
TVF4-3	1.61	11.09	1200	0.10
ZGF4-1	1.54	11.89	1150	0.09
ZGF4-2	1.31	8.32	1100	0.08
ZGF4-3	1.29	9.80	1080	0.08

3.1.3. Graphical Comparative Analysis

Figures 4-8 illustrate the typical Force-Displacement ($F - \delta$) curves obtained for representative specimens from each configuration. These plots reveal distinctive structural behaviors, including possible plastic plateaus and either progressive or brittle failure modes.

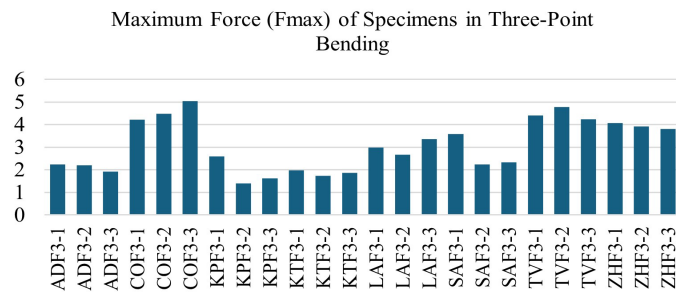


Figure 4. Maximum force (F_{max}) in three-point bending tests.

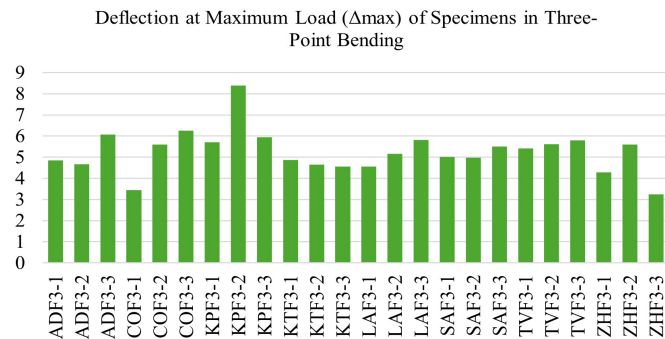


Figure 5. Displacement at maximum load (Δ_{max}) in three-point bending tests.

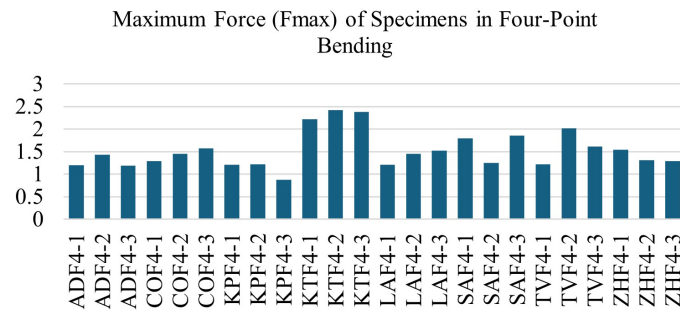


Figure 6. Maximum force (F_{max}) in four-point bending tests.

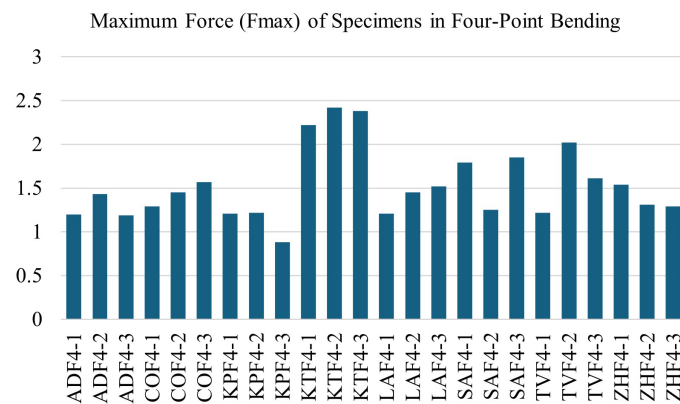


Figure 7. Displacement at maximum load (Δ_{max}) in four-point bending tests.

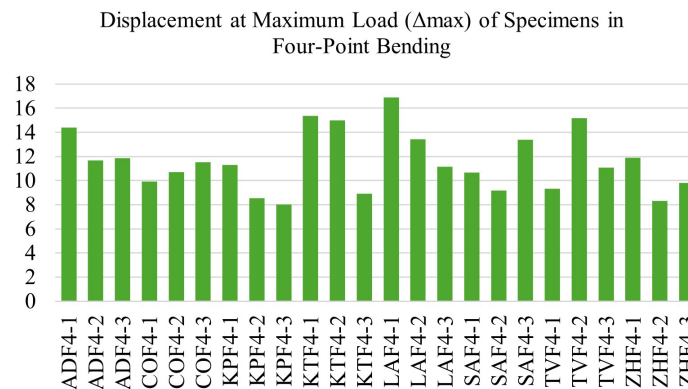


Figure 8. Displacement at maximum load (Δ_{max}) of specimens in four-point bending.

3.2. Discussion

The results obtained from the three-point bending (3P) and four-point bending (4P) tests reveal significant variability in the mechanical performance of the tested specimens. This variability is attributable to the inherently heterogeneous nature of bamboo as a material, as well as the specific configuration of the assemblies.

The average apparent modulus of elasticity values observed range from 1080 MPa to 4600 MPa, depending on the specimen type. The COF3 series exhibited the highest performance, with an average modulus of 4333 MPa. A moderate to high dispersion in values was observed, reflecting the influence of morphological

irregularities in the bamboo, particularly wall thickness, presence of nodes, and longitudinal uniformity.

The geometry of the specimens directly influenced mechanical behavior. Rigid configurations such as the COF3 samples, which were well-balanced in the transverse direction, displayed a more linear behavior with sharp fracture modes. In contrast, sandwich-type specimens (TVF4, ZGF4) exhibited more ductile behavior, characterized by larger displacements prior to failure.

Compared to commonly used tropical hardwoods such as iroko or framiré, which exhibit modulus values around 4000 - 4500 MPa, the performance of the COF3 bamboo specimens places the local bamboo within a comparable—if not superior—range in some cases, making it a credible candidate for structural applications.

These findings support the hypothesis that bamboo can be effectively integrated into timber-concrete composite floor systems, particularly as a flexural load-bearing element. The combination of high modulus values and good energy dissipation capacity reinforces the potential of bamboo in sustainable construction contexts.

Among the main limitations of this study, one should note the limited number of specimens tested, the absence of complementary tensile and compression tests, and the exclusive use of standard laboratory conditions. Future investigations should address these aspects, including the evaluation of long-term behavior under variable hygrometric conditions.

4. Conclusions

This experimental study aimed to explore the potential of locally sourced bamboo as an engineering material for wood-concrete composite structures, through an initial phase focusing on flexural behavior. The tests, conducted under two protocols (three-point and four-point bending), yielded several significant insights.

In three-point bending, mechanical performance varied depending on the type of assembly, with modulus values reaching up to 4600 MPa in reinforced configurations. The observed energy dissipation capacity indicates appreciable structural toughness, although it depends on the assembly method.

Four-point bending, which more accurately reflects real-world loading conditions in floor elements, revealed lower overall stiffness but more homogeneous behavior. This configuration confirmed the technical interest of sandwich structures in limiting deformability while ensuring even stress distribution.

The results validate the relevance of local bamboo as a secondary or composite material for sustainable construction, particularly in tropical regions with abundant bamboo resources. The combination of locally available bio-based materials and rigorous characterization paves the way for innovative, low-carbon construction applications.

Nonetheless, additional investigations are necessary. These should include tensile and compression tests, long-term performance analysis (aging, humidity), in-

terface behavior studies between bamboo and concrete, and development of anchorage or connector systems. Such future research will help refine modeling approaches and secure the integration of bamboo into composite structural systems.

Acknowledgements

The authors are grateful to all laboratory technicians of “Laboratoire d’Énergétique et de Mécanique Appliquées (LEMA)” of University of Abomey-Calavi (UAC), Benin.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Akoègninou, A., van der Burg, W.J. and van der Maesen, L.J.G. (2006) Analytical Flora of Benin. Backhuys Publishers.
- [2] Adomou, A.C., Akoègninou, A., Sinsin, B., de Foucault, B. and van der Maesen, L.J.G. (2008) Semi-Deciduous Forest Remnants in Benipatterns and Floristic Characterization. *Acta Botanica Gallica*, **156**, 159-171.
<https://doi.org/10.1080/12538078.2009.10516148>
- [3] EN 310 (1993) Wood-Based Panels—Determination of Modulus of Elasticity in Bending and of Bending Strength. European Standard. AFNOR.
- [4] Hargot, T. (2009) The Use of Bamboo in Construction—Characteristics and Applications. *Bois et Forêts des Tropiques*, No. 300, 25-35.
- [5] Liese, W. and Köhl, M. (2015) Bamboo: The Plant and Its Uses. Springer.
<https://doi.org/10.1007/978-3-319-14133-6>
- [6] International Organization for Standardization (2021) Bamboo Structures—Bamboo culms—Structural Design.
<https://www.iso.org/obp/ui/en/#iso:std:iso:22156:ed-2:v1:en>
- [7] Li, S., Yang, Q.Y., Sun, X.Z., Shang, L.L., Yang, S.M. and Jiang, Z.H. (2025) The Behavior and Mechanism of Longitudinal Liquid Permeation in Moso Bamboo (*Phyllostachys edulis*). *Industrial Crops & Products*, **232**, Article ID: 121255.
<https://doi.org/10.1016/j.indcrop.2025.121255>
- [8] Huang, Y.X., Ji, Y.H. and Yu, W.F. (2019) Development of Bamboo Scrimber: A Literature Review. *Journal of Wood Science*, **65**, Article No. 25.
<https://doi.org/10.1186/s10086-019-1806-4>