Advances in Bamboo Science 12 (2025) 100195

Contents lists available at ScienceDirect

Advances in Bamboo Science

journal homepage: www.journals.elsevier.com/advances-in-bamboo-science

Physical, mechanical and durability properties of *Bambusa vulgaris* Schrad. ex J.C.Wendl.: implications for sustainable construction in Nigeria

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ARTICLE INFO

Keywords:
Bamboo
Bambusa vulgaris species
Climate change
Mechanical properties
Durability
Sustainable construction

ABSTRACT

The incidence and severity of climate-related problems such as flooding, erosion and extreme heat are increasing across the globe. Such problems are in part attributed to the construction industry's dependency on high CO_2-emission materials such as concrete and steel. Although there is a range of alternative materials, such as bamboo, which are in abundant supply, have low carbon footprints and are great thermal insulators, their use is quite low in Nigeria. We investigated how bamboo, specifically *Bambusa vulgaris*, from Abuja, Nigeria, could help meet the demands of building construction while being resilient to climate change. Laboratory tests were done to establish the physical, mechanical and durability properties of bamboo to evaluate its performance under different environmental conditions. Average water absorption percentages for fresh and dry bamboo samples were determined to be 16.0 % and 19.1 %, respectively, with moisture content averaging at 28.0 % and 17.7 %, respectively. The dry specimens had the greatest tensile strength, with a value of 84.8 MPa. The average compressive strengths were 13.7 MPa and 16.6 MPa for fresh and dry bamboo samples, respectively. We provide quantitative information on the physical and mechanical properties of *Bambusa vulgaris*, demonstrating its structural performance and environmental impact as well as its sustainability and potential ability to counteract the negative effects of climate change. Our research will assist in the formulation of building regulations and standards in addition to encouraging the use of bamboo in eco–friendly construction uses.

1. Introduction

With the impacts of climate change increasing, there is a growing need for strong and sustainable building materials in housing projects across Nigeria. According to the latest UNEP "Global Status Report for Buildings and Construction", the construction industry contributes significantly to global CO_2 emissions, accounting for roughly 37 % of energy and process-related CO_2 emissions and 34 % of global energy demand. This translates to around 21 % of total global greenhouse gas emissions attributed to the building sector as a whole (United Nations Environment Programme (UNEP, 2023). Nigeria is dealing with some big challenges, including rapid urbanization and environmental issues, so, it is important to find new construction methods that can help in building durable homes that are more environmentally friendly. Apart from steel, timber, concrete, glass, sandcrete blocks and aluminium, one material that is catching attention is bamboo (*Bambusa vulgaris* Schrad. ex J.C.Wendl.). Standing out amongst potential building materials, it has major potential to boost climate resilience and sustainability in the construction world. It could make a huge difference in how buildings are being advanced in Nigeria, especially as these pressing challenges are being faced (Kumar Boity et al., 2022). As the impacts of climate change are becoming more obvious, the call for resilient and eco-friendly materials in housing projects is more urgent than ever. There is need to be creative with construction methods, and bamboo could lead to homes being more durable and environmentally friendly (Bredenoord, 2024).

Bamboo is a fast-growing and renewable resource that has lots of benefits. Compared to conventional construction materials, bamboo offers significant advantages, including lower carbon emissions, rapid renewability and superior adaptability to extreme weather conditions. For example, it has high tensile strength and is quite flexible, so can withstand earthquakes and strong winds. In addition, it is important for sequestering carbon and could help reduce the use of traditional, energy-intensive building materials, consistent with the drive towards greater global sustainability. Using bamboo could also boost local

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https://doi.org/10.1016/j.bamboo.2025.100195
Received 22 December 2024; Received in revised form 10 August 2025; Accepted 15 August 2025
Available online 16 August 2025

economies by supporting local industries and creating jobs, while being kinder to the environment during construction. With climate change, there is a need to rethink how construction is carried out. It is crucial to incorporate climate resilience into construction methods (Elhegazy et al., 2024), for example by looking at how adaptive designs and materials can deal with extreme weather. Climate-resilient construction practices are about using smart strategies and materials throughout the design, building and upkeep of structures (Abera, 2024). In the bigger picture, the construction industry needs to respond proactively rather than reactively to the growing frequency and intensity of extreme weather, rising temperatures and other climate-related challenges.

Traditional building methods take a toll on the environment. Windapo et al. (2021) explored how conventional construction practices impact the planet, pointing out how urgent it is to find sustainable alternatives. There is a need to move towards greener construction practices if the wide range of environmental issues is to be addressed. This shift could involve the use of eco-friendly materials, investing in energy-efficient technology, cutting down on waste and taking into account the full life cycle of buildings. The idea behind sustainable construction is to meet today's needs without compromising the needs of future generations. It is about taking responsibility for the environment in the construction world. Traditional methods often fail to consider long-term sustainability, instead focussing on immediate costs and how quickly work can be completed, rather than the environmental impacts of the materials and techniques used.

Climate change has increased the risk of infrastructure failure. Castaño-Rosa et al. (2022) examined the risks associated with climate impacts on construction, stressing how crucial resilient designs are to tackle these challenges. More and more extreme weather events such as hurricanes, floods and heat waves do not occur in a vacuum. They can wreak havoc on infrastructure, damaging it or affecting its strength. More frequent heatwaves or sudden cold snaps can adversely affect the performance of infrastructure. Heatwaves can destroy road surfaces or railway tracks whereas freezing temperatures can severely disrupt water supply systems. With precipitation, some areas may be affected by heavy rainfall events, leading to flooding that can damage bridges and roads. Others may experience drought, impacting water supply systems. In addition, increasing temperatures lead to thermal expansion, with materials such as concrete and metal expanding. The situation is complicated by the unpredictability of natural disasters and their growing intensity. The climatic events not only directly damage infrastructure but can also slow down recovery efforts, increasing the complexity of infrastructure management.

While Nigerian bamboos, particularly *Bambusa vulgaris,* demonstrate useful mechanical properties for construction, some species growing elsewhere, such as *Dendrocalamus brandisii* (Munro) Kurz*,* may offer superior flexural strength (Adedipe et al., 2013). However, with proper treatment and design considerations, many bamboos in Nigeria remain a viable and sustainable alternative for building applications, supporting global initiatives to promote eco-friendly construction materials. This study explores the potential of *Bambusa vulgaris*, a species introduced to Nigeria from Southeast Asia, as a sustainable building material for climate-resilient construction. We aimed to determine the physical properties of bamboo, assessing its mechanical characteristics, and evaluating its durability for application in the construction industry. This study supports the development of building regulations and standards while promoting bamboo as a sustainable material for eco-friendly construction.

2. Background

2.1. Understanding climate change

"Climate change" has replaced "global warming" in common parlance, as the latter poorly describes real-world weather patterns. The term "climate change" describes a shift in the climate over time, whether brought on by human action or natural variability, with global ramifications (Onoja et al., 2011). Climate change conditions specific to the construction industry are related to climate amplitude and duration (Oruc et al., 2024). As an example, extreme heat or cold may require supplementary systems which are resistant to these temperatures, leading to budget over runs. From a temporal perspective, such conditions may persist much longer than in the past, for example, daytime temperatures more than 38 °C for 90 consecutive days. Consequently, outside workers may need to be rotated more frequently or given less work, slowing completion rates and adding labour costs.

2.2. Sustainable construction materials and practices

Sustainable construction materials and techniques have become essential in the worldwide movement to develop sustainable built settings that are environmentally and socially sustainable. Such materials and methods are designed to have the lowest impact, use fewer resources, work better and last longer. Many studies have contributed substantially to the field, discussing sustainable materials, practices, findings, and advice at large (e.g., Oruc et al., 2024; Sun and Zheng, 2017).

Bamboo is a nature-based solution that absorbs more carbon dioxide than most other plants, thereby helping to reduce greenhouse gases and greenhouse gases (Pan et al., 2023). Our study emphasizes bamboo's potential in reducing the construction industry's environmental impact, and in turn, the potential for a more sustainable and eco-friendlier built environment.

Liese and Tang (2015) examined the material properties of bamboo, highlighting bamboo's very high strength-to-weight ratio and versatility. They discussed the lightness and availability of bamboo material and the fact that it can be manipulated easily using regular tools on-site, thus making it usable for a wide range of structural applications, from houses to bridges. They also emphasized bamboo's rapid growth and renewability, making it an economically viable construction material, particularly in rural areas between the 30-degree north and south latitudes, where many other resources are limited.

Bamboo components are being utilized by the construction industry (Obianyo et al., 2023). Although bamboo elements have a slight flexibility, making them less rigid than concrete or steel, the appropriate engineering should enable bamboo to be used in modern buildings. Research has demonstrated ways of overcoming bamboo's drawbacks, such as deflection, by inventing new designs and engineering solutions. Isukuru et al. (2023) point out the economic and environmental advantages of using bamboo for construction. Their research demonstrates that bamboo can benefit rural economies through employment creation and resource management. Their study further showed that bamboo can be used as a substitute for conventional building materials, decreasing the environmental impact of the construction industry. Overall, bamboo is gaining increasing attention as a sustainable construction material due to its impressive physical and mechanical properties.

The density of bamboo varies depending on the species and age, but it is generally lightweight, contributing to ease of handling and transportation (Chaudhary et al., 2024). Its moisture content significantly affects its mechanical properties (Zhao et al., 2024). Consequently, it is important to manage moisture levels to prevent shrinkage, swelling and decay. Bamboo's unique fibre structure, with longitudinally oriented vascular bundles, provides its exceptional strength and flexibility (Gao et al., 2022; Xu et al., 2024). The natural durability varies between species. Generally, treatments are needed to improve resistance to insects and fungi (Chen et al., 2025). Bamboo exhibits high tensile strength, comparable to some steel alloys. This makes it excellent for applications requiring resistance to pulling forces. It also possesses significant compressive strength, allowing it to withstand heavy loads. In some species, the compressive strength can exceed that of concrete. Bamboo's flexibility and resilience make it suitable for structures subjected to bending forces, such as those in earthquake-prone regions (Bin

Azuwa, 2024).

Bamboo is fast growth and renewability are pointed out as key factors that are consistent with worldwide objectives to support sustainability and resiliency in architecture indicating the importance of bamboo in the urban development sector, especially in the global south (Janssen, 2000). Sharma et al. (2015) highlighted the possibilities and issues associated with bamboo construction. Their research highlighted the most critical factors hindering the adoption of bamboo, such as the absence of formal regulations, and a lack of knowledge about architectural techniques involving bamboo. At the same time, they identified many opportunities for innovation in bamboo construction; this would stimulate its integration into the regular infrastructure sector. Bamboo is unique among other materials in its versatility and strength-to-weight ratio. It can be used structurally. It represents an alternative form of construction for structures ranging from scaffolding to small cottages. It stands out for the durability and robustness of its components despite the material being exceptionally light. Many kinds of buildings, bridges, and other structural works could usefully exploit bamboo. Furthermore, it is not only affordable, but also widely available in many parts of the world. Bamboo construction offers a sustainable alternative to conventional methods by sequestering carbon, reducing energy consumption, promoting rapid renewability, enhancing thermal efficiency, increasing resilience to climate-induced disasters, minimizing waste, conserving water, and adapting to diverse climates, making it an effective solution for mitigating the effects of climate change (Isukuru et al., 2023).

3. Methodology

We applied a laboratory experiment method to derive the physical, mechanical and durability properties of bamboo (*Bambusa vulgaris*), using culms at least 4 years old bamboo and culm sections of at least 76 mm diameter and 150 mm length. The green and dry bamboo samples were obtained from the building materials market in Jabi, Abuja, Nigeria. While a range of species are available at the market, we chose *Bambusa vulgaris* as it is one of the common species of bamboo in the study location. Each piece of the bamboo was classified into two subgroups:

- Green Bamboo: Freshly cut bamboo with high moisture content (12 specimens).
- Dry Bamboo: Bamboo that had been air-dried to reduce its moisture content (12 specimens).

Both green and dry bamboo were used to assess the impact of moisture content on various mechanical and physical properties.

Cutting and Shaping: The samples used for the study were measured before cutting as shown in Fig. 1a while the required sizes and forms of the bamboo for compressive strength test were cut out as shown in Fig. 1b. In tensile testing, "dog bone" specimens were prepared as shown in Fig. 1c. The dog-bone shape was dimensioned according to the requirements of ISO 22157:2019 standard, and all tests and procedures were done in accordance with ISO 22157: 2019 (Gauss et al., 2019). The bamboo samples used for the study are shown in Fig. 1d.

3.1. Methods

3.1.1. Tensile test

The tensile test was conducted to determine the tensile strength, elongation at break, and Young's modulus, following the ISO 22157:2019 (Gauss et al., 2019) standards. The test included 24 specimens of bamboo: 12 green and 12 dry. The specimens were prepared a standardized "dog-bone" form with a gauge length of 150 mm, and a

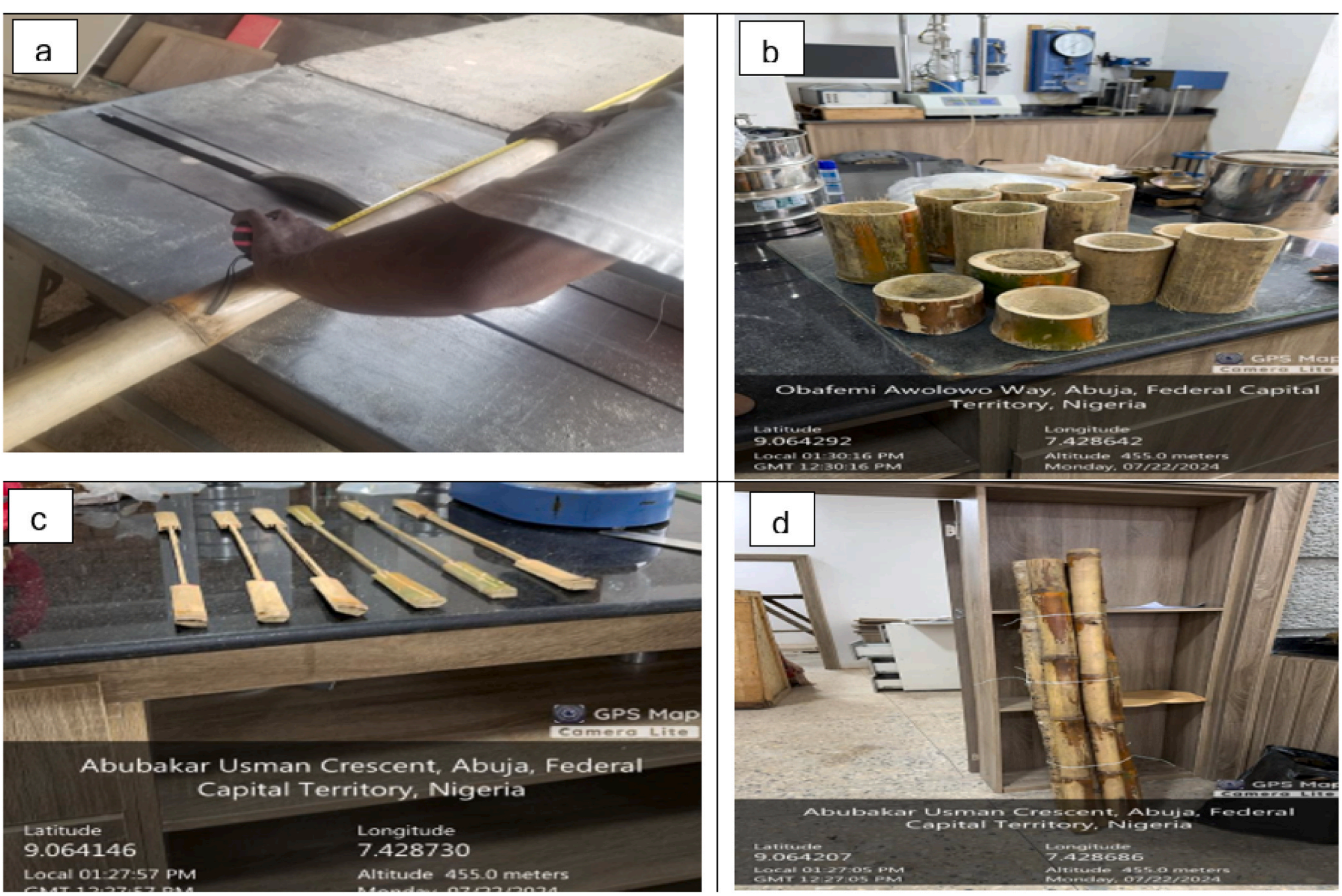

Fig. 1. Preparation of bamboo test specimens.

width of 20 mm at the narrowest point, based on the dimensions defined by the standard. Defect-free bamboo sections were selected, cut into the required shape, and then sanded and trimmed to ensure uniformity. After the test, the maximum tensile load and elongation at break were recorded. Tensile strength (σ) was calculated using the Formula 1:

$$\sigma = \frac{F_{max}}{A} \quad (1)$$

where,

F_{max} is the maximum load recorded during the test; and

A is the cross-sectional area of the specimen.

Elongation at break was measured as the difference between the initial and final gauge lengths of the specimen. Young's modulus (E) was determined by calculating the slope of the linear portion of the stress-strain curve, using the Formula 2:

$$E = \frac{\Delta\sigma}{\Delta \in} \quad (2)$$

where,

$\Delta\sigma$ is the change in stress; and

$\Delta\epsilon$ is the change in strain over the linear region of the curve.

Stress-strain curves and data presented in tabular form were used to compare the tensile properties for green bamboo and dry bamboo samples. Any irregularities or abnormalities detected during testing were observed and recorded.

3.1.2. Bending test

The bending test was used to determine bending strength and modulus of elasticity. The dog-bone shape was dimensioned according to the requirements of the ISO 22157:2019 standard, and all tests and procedures were done in accordance with ISO 22157: 2019 (Gauss et al., 2019). This indicates that the length of the specimen should be the smaller of two values: the outer diameter (D) or 10 times the wall thickness (10 t). Defect-free culm sections were chosen, cut to the correct dimensions, and then checked to ensure that all the pieces were the same shape. The maximum load and deflection at the middle were then registered. Bending strength (σ) was determined from Formula 3:

$$\sigma = \frac{3FL}{2bd^2} \quad (3)$$

where,

F is the maximum load applied at failure;

L is the span length between the supports;

b is the width of the specimen; and

d is the depth (height) of the specimen.

The deflection was determined from the load-time curve using Formula 4:

$$\delta = \frac{LR\ X\ T}{\sigma} \quad (4)$$

where,

LR is the load rate in N/mm;

T is the time in seconds; and

σ is the stress at maximum load.

Results, including bending strength and deflection, were recorded, and the bending properties of green and dry bamboo were compared.

3.1.3. Compressive test

A compressive strength test was used to determine compressive strength and deformation. The 24 specimens used for the test were prepared as 12 green and 12 dry specimens. Each specimen was cut into cylindrical and cuboidal shapes, with dimensions as specified above. The cylinders had a length-to-diameter ratio of 2.

The compressive strength test was done using a universal testing machine (UTM) with a compression set that included platens that applied uniform pressure to each specimen. The specimens were sandwiched between the compression platens as shown in Fig. 2, and the centring and alignment steps were followed to avoid possible off-centred loading.

After the test, the maximum compressive load and the corresponding deformation were recorded. Compressive strength was calculated using Formula 5:

$$\sigma = \frac{F_{max}}{A_{culm}} \quad (5)$$

where,

F_{max} is the maximum load recorded during the test; and

A is the cross-sectional area of the specimen.

The cross-sectional area was calculated as:

$$A_{culm} = \frac{\pi D^2}{4} \quad (6)$$

where, D is the diameter of the cylinder.

Compressive strength results were documented and analysed to compare the properties of the green and dry bamboo specimens.

3.1.4. Moisture content test

The water content test determined the moisture content in the specimens, a crucial factor in ascertaining the material's suitability and performance in different environmental conditions. This test was conducted in line with standard procedures to ensure accurate and reliable results. Twenty-four bamboo specimens were prepared: 12 green and 12 dry test specimens. The specimens were cut into standardized cylindrical samples to aid the uniform testing.

The moisture content of the bamboo specimens was calculated using Formula 7:

$$MC = \frac{W_{wet} - W_{dry}}{W_{wet}} X \quad 100 \quad \% \quad (7)$$

where,

W_{wet} is the initial weight of the specimen; and

W_{dry} is the weight after drying.

The results were documented and analyzed. This analysis helped assess the effectiveness of the drying process and provided insights into the actual potential impact of moisture on the material properties of bamboo.

3.1.5. Water absorption test

A water absorption test was conducted to determine the capacity of the specimens to absorb water, an important indicator of the material's behaviour in humid conditions. The test was conducted in accordance with standard procedures to ensure accuracy and reliability. Six bamboo specimens were used for the test: 3 green and 3 dry specimens. The specimens were cut into standardized cylindrical shapes, to ensure uniformity in testing.

The water absorption was calculated using Formula 8:

$$WA = \frac{W_f - W_i}{W_i} X \quad 100 \quad (8)$$

where,

W_f is the mass of the sample with absorbed water; and

W_i is the mass of the dry sample.

The results were documented and analyzed to evaluate the performance of bamboo under wet conditions. This analysis provided insights into the material's susceptibility to moisture and potential implications for its use in construction.

3.1.6. Shrinkage test

The shrinkage test was conducted to measure the dimensional

Fig. 2. Compressive strength test specimens and set up.

changes in bamboo specimens due to moisture variation, and specifically to determine the shrinkage that occurs as the bamboo dries. This test followed standard procedures to ensure accurate and reliable results. Twenty-four bamboo specimens were prepared: 12 green and 12 dry specimens. Each specimen was cut into a standardized cylindrical shape to ensure uniform testing.

The procedure for the shrinkage test involved measuring the dimensions of the specimens before and after drying. Initially, the dimensions of each green bamboo specimen were measured using Vernier callipers. These initial dimensions were recorded as the wet measurements (L_{wet}, W_{wet}, H_{wet}), where L, W and H represent the length, width and height of the specimen, respectively.

The specimens were then dried in an oven at a temperature of 105°C until they reached a constant weight, indicating that all moisture had been removed. This drying process typically took several hours. After drying, the specimens were cooled in a desiccator to prevent moisture absorption from the air. Once cooled, the dimensions of each dried specimen were measured again. These measurements were recorded as the dry dimensions (L_{dry}, W_{dry}, H_{dry}).

The shrinkage in each dimension was calculated using Formula 9:

$$\text{Shrinkage} = \frac{D_{wet} - D_{dry}}{D_{dry}} X \quad 100 \tag{9}$$

The results were documented and analyzed to assess the impact of drying on the specimens. This analysis provided insights into the material's dimensional stability and its suitability for use in environments with varying moisture conditions.

4. Results and discussion

4.1. Mechanical properties

The results of the mechanical strength of the green and dry specimens are summarized in Table 1. These include tensile strength, compressive strength, bending strength, elastic modulus in tension and deflection in bending. Three specimens were labelled as Ga, Gb and Gc for green bamboo while three specimens were also labelled as Da, Db and Dc for dry bamboo. Thus, samples Ga, Gb and Gc are replications for green bamboo while samples Da, Db and Dc are replications for dry bamboo.

4.2. Tensile strength test parameters

The tensile strength analysis of the specimens, presented in Fig. 3, showed significant differences between green and dry bamboo, underscoring the influence of moisture content on its mechanical behaviour. Green bamboo gave an average tensile strength of 54.372 MPa, whereas dry bamboo showed a markedly higher tensile strength of 82.474 MPa. This substantial increase in tensile strength upon drying is consistent with findings from recent studies (Al-Rukaibawi and Károlyi, 2023; Bin Azuwa, 2024) that report tensile strength values for dry bamboo within a similar range.

For maximum tensile force, green specimens gave forces of 2.428 kN, 3.345 kN and 2.383 kN, while dry specimens showed significantly higher forces of 3.918 kN, 4.238 kN and 4.215 kN. These results are

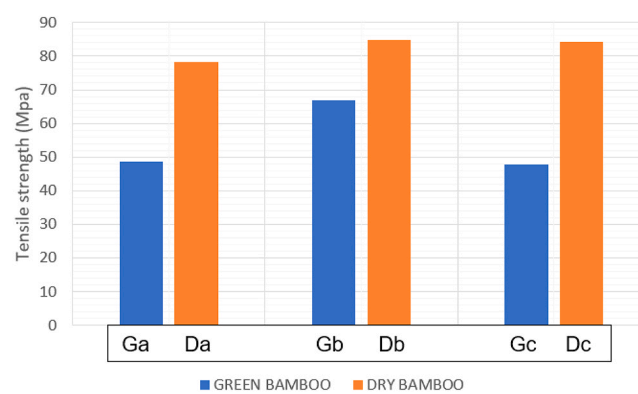

Fig. 3. Tensile strength of the green and dry specimens.

Table 1
Summary of mechanical properties of the green and dry bamboo sample.

Mechanical strength test parameter	Green bamboo			Dry bamboo		
	Ga	Gb	Gc	Da	Db	Dc
Tensile strength (MPa)	48.568	66.896	47.652	78.351	84.765	84.307
Av. tensile strength (MPa)	54.372			82.474		
Compressive strength (MPa)	12.112	14.210	14.899	15.837	17.412	16.614
Av. compressive strength (MPa)	13.741			16.621		
Bending strength (MPa)	15.9	14.3	12.9	6.6	6.1	8.5
Av. bending strength (N/mm^2)	14.37			7.07		
Elastic modulus (MPa)	6572	6594	6618	2405	2509	2219
Av. elastic modulus (MPa)	6595			2378		
Deflection at maximum force (mm)	0.877	0.899	0.792	0.808	0.813	0.718
Av. deflection at maximum force (mm)	0.856			0.780		

consistent with the findings of Bin Azuwa (2024), who reported that dry bamboo exhibits higher tensile force resistance compared to green bamboo.

The bending strength test results for the bamboo specimens shown in Fig. 4 reveal clear differences between green and dry bamboo, illustrating how moisture content influences its mechanical properties. Green bamboo exhibited a higher average bending strength of 12.23 MPa compared to 7.07 MPa for dry bamboo and this can be attributed to its moisture-induced flexibility. This trend is supported by recent studies such as those by Bin Azuwa (2024).

4.3. Compressive strength test results

The compressive strength test results are presented in Fig. 5. Green bamboo was measured at 12.112 MPa, 14.210 MPa, and 14.899 MPa, averaging 13.741 MPa. Dry bamboo exhibited compressive strengths of 15.837 MPa, 17.412 MPa, and 16.614 MPa, with an average of 16.621 MPa. This indicates an increase in compressive strength when bamboo is dried, similar to the results of Bin Azuwa (2024).

4.4. Physical test results

The results of the physical properties of the green and dry specimens are summarized in Table 2. These include moisture content, density, water absorption, shrinkage and thermal cycling.

4.4.1. Moisture content test results

Green bamboo and dry bamboo had different amounts of moisture (Fig. 6). For green bamboo, the moisture levels were 30.948 %, 31.491 % and 29.436 %, which averages to 30.625 %. On the other hand, dry bamboo had moisture levels of 17.744 %, 18.035 % and 17.265 %, with an average of 17.680 %.

4.4.2. Water absorption test results

The water absorption test results for bamboo samples showed a clear difference between green and dry bamboo, as shown in Fig. 7. Green bamboo absorbed water at percentage mass of 14.907 %, 18.417 %, and 14.764 %, with an average of 16.030 %. In contrast, dry bamboo absorbed water more quickly, at rates of 19.504 %, 20.799 %, and 16.877 %, averaging 19.060 %. This shows that green bamboo absorbs less water than dry bamboo.

4.4.3. Shrinkage test results

The measurements of how much bamboo shrinks in different directions provides useful information about its size stability. For green bamboo, the shrinkage across the width (radial) was 4.757 %, 5.714 % and 5.714 %, with an average of 5.236 % as shown in Fig. 8. On the other hand, for dry bamboo, the shrinkage across the width was smaller, with values of 4.252 %, 4.343 %, and 3.488 %, averaging 4.028 %. The shrinkage along the length (axial) for green bamboo was 0.406 %, 0.381 % and 0.329 %, averaging 0.372 %, while dry bamboo had even less shrinkage along the length, with values of 0.227 %, 0.300 %, and 0.241 %, averaging 0.256 %. The shrinkage around the circumference (tangential) could not be measured because the testing temperature affected the samples. The wall thickness of the samples was not measured in the shrinkage test because changes in the wall thicknesses of the samples due to shrinkage was not considered as a critical factor affecting the properties being researched in this study.

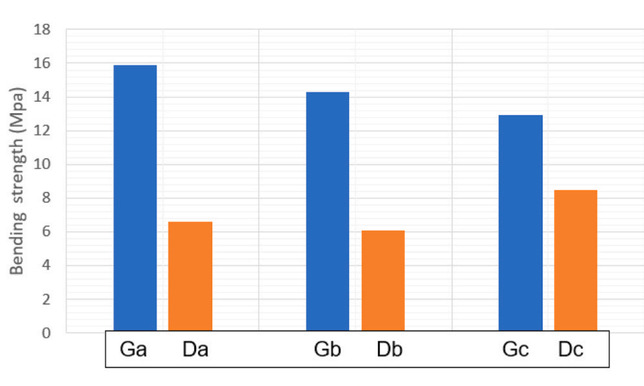

Fig. 4. Bending strength of the green and dry specimens.

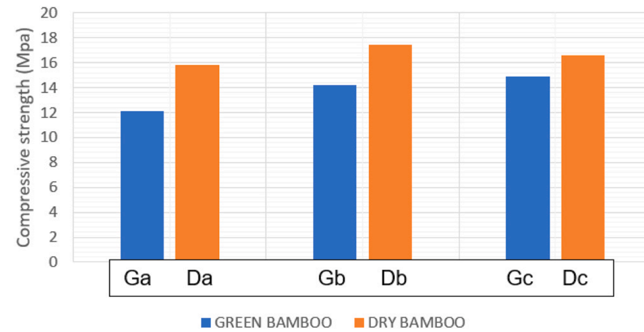

Fig. 5. Compressive strength properties of the green and dry specimens.

5. Conclusions

We drew the following conclusions from our study. Green bamboo has a higher bending strength compared to the dry bamboo. We conclude that the moisture content of bamboo (*Bambusa vulgaris*) plays critical role to the performance of the bamboo as it affects how strong and stiff the bamboo is. Dry bamboo is stronger when pulled or pushed, but it is not as flexible as green bamboo. The high tensile and compressive strength of dry bamboo indicates that the moisture content affects its tensile and compressive strength.

Fresh green bamboo is more flexible and can stretch more, which could be helpful in applications that need to bend or absorb shocks. The type of bamboo to use – green or dry – depends on the application, Dry bamboo can be used for applications that require high tensile and compressive strength, while green bamboo can be used for applications that require for flexibility such as high bending strength.

Bambusa vulgaris could be a good eco-friendly choice to replace steel in buildings, especially for cheaper, smaller buildings. But it has some problems, including durability, moisture absorption and poor performance in bigger, more difficult projects. More research is needed to make bamboo better by treating it and combining it with other materials, so it can be used more often in green building projects.

Bambusa vulgaris has a high tensile strength-to-weight ratio, often compared favorably to steel. However, the tensile strength varies significantly with species, moisture content and treatment. Steel, while heavier, provides a consistent and predictable tensile strength, which is crucial for designing load-bearing structures. Our results indicate that green bamboo has a greater degree of flexibility than dry bamboo. Therefore, we conclude that the moisture content of the culm affects its mechanical properties.

Our research highlights the need for expanded investigations into *Bambusa vulgaris* and other bamboo species, facilitating a thorough understanding through comparative studies. Our study could support the development of building regulations and standards while promoting bamboo as a sustainable alternative for eco-friendly and climate-resilient construction.

CRediT authorship contribution statement

Abubakar Dayyabu: Validation, Supervision. **Abraham Orianegbena Osezuah:** Writing – original draft, Methodology,

Table 2
Summary of the physical properties.

	Green Specimens Ga Gb Gc			Dry Specimens Da Db Dc		
Moisture content (%)	30.948	31.491	29.436	17.744	18.035	17.265
Av. moisture content (%)	30.625			17.680		
Density (Kg/m^3)	388	356	298	354	352	353
Av. density (Kg/m^3)	347			353		
Water absorption (%)	14.907	18.417	14.764	19.504	20.799	16.877
Av. Water absorption (%)	16.030			19.060		
Radial shrinkage (%)	4.757	5.714	5.714	4.252	4.343	3.488
Av. radial shrinkage (%)	5.236			4.028		
Axial shrinkage (%)	0.406	0.381	0.329	0.227	0.300	0.241
Av. axial shrinkage	0.372			0.256		

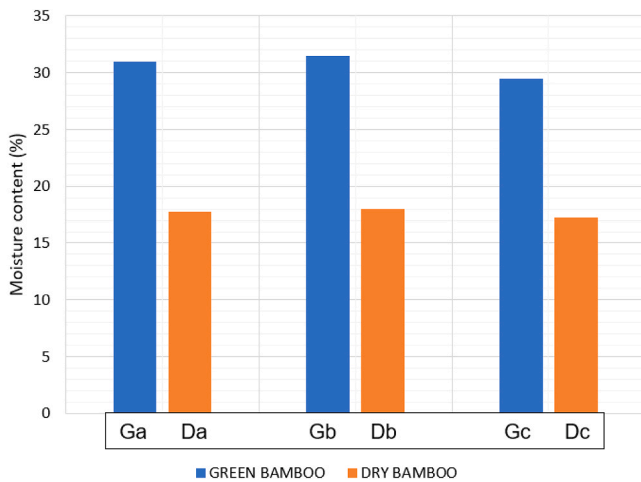

Fig. 6. Moisture content of the green and dry specimens.

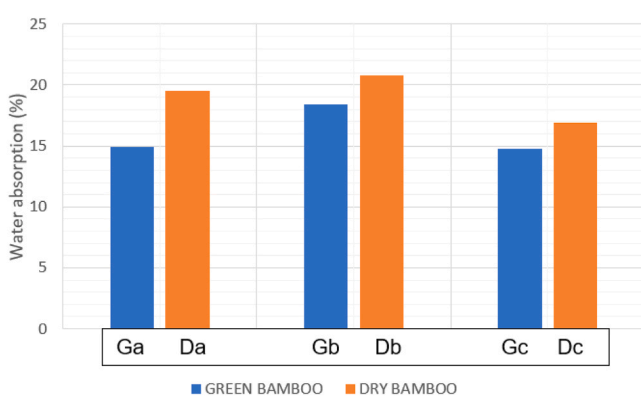

Fig. 7. Water absorption test results of the green and dry bamboo specimens.

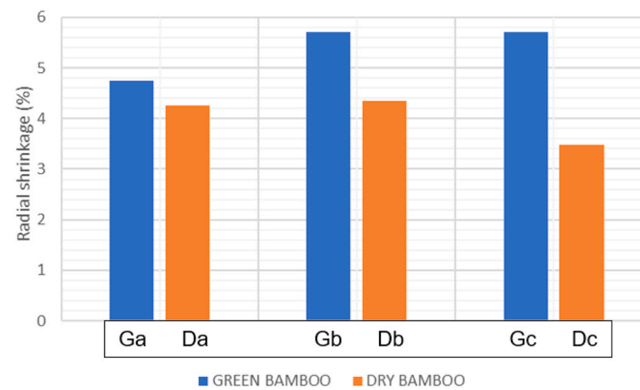

Fig. 8. Shrinkage test results of the green and dry specimens.

Investigation, Formal analysis, Conceptualization. **Ifeyinwa Ijeoma Obianyo:** Writing – review & editing, Supervision, Project administration, Conceptualization. **Abdulganiyu Sanusi:** Writing – review & editing, Validation, Methodology. **Anthony Muoka:** Writing – review & editing, Validation. **Assia Abuobakar Mahamat:** Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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