
**East African Journal of Forestry & Agroforestry**
eajfa.eanso.org
**Volume 7, Issue 1, 2024**
**Print ISSN: 2707-4315 | Online ISSN: 2707-4323**
Title DOI: https://doi.org/10.37284/2707-4323

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

*Original Article*

# Morphological Characteristics and Growth Performance of Bambusa vulgaris Schrad. Ex J. C. Wendl in Selected Agro-Ecologies of Uganda

*Fred Kalanzi[1*], Isaac Kiyingi[1], Christine Kalembe Mwanja[1], Hillary Agaba[1], Michael Malinga[2], Selim Reza[3] & Durai Jayaraman[4]*

[1] National Agricultural Research Organisation, P. O. Box 295, Entebbe, Uganda.
[2] International Bamboo and Rattan Organisation C/O 10/20 Spring Road, Bugoloobi P. O Box 70863, Kampala Uganda.
[3] International Bamboo and Rattan Organisation, East African Regional Office, 9th Floor, Building 2, Yobek Commercial Center Addis Ababa Ethiopia.
[4] International Bamboo and Rattan Organisation, 8 Futong Dong Da Jie, Wangjing, Chaoyang District, Beijing 100102, P.R. China.
[*] Author for Correspondence ORCID ID: https://orcid.org/0000-0003-1074-9675; email: kalfrem@gmail.com

**Article DOI: https://doi.org/10.37284/eajfa.7.1.1802**

**Date Published:**

*08 March 2024*

**Keywords**:

*Growth Characteristics, Agro-Ecological Conditions, Height, Wall Thickness, Culm Diameter.*

ABSTRACT

Bamboo is a versatile and valuable resource that has been shown to have social, ecological, and economic benefits in many countries worldwide. Even though Uganda has a suitable environment for bamboo growth, it remains underutilized. One of the key challenges in promoting bamboo farming is the need for more information about the growth performance of different bamboo species in various site conditions. Therefore, this study determined the morphological characteristics and growth performance of *Bambusa vulgaris* in Uganda. A total of 24 bamboo farms were selected from a list of bamboo farmers provided by key informants using stratified sampling. These farms had relatively uniform *B. vulgaris* stands and were drawn from Uganda's three agro-ecological zones (AEZs): the Southwestern, West Nile, and Lake Victoria crescent agro-ecological zones. Eight temporary sample plots were established in each zone, and various growth parameters were measured. One-way Analysis of Variance (ANOVA) followed by Sidak post-hoc test was used to compare the performance of *B. vulgaris* across the different agro-ecological zones based on growth parameters. The results of the study showed that the total above-ground biomass was highest in the Lake Victoria crescent (24.773 kg/ha), followed by the West Nile (17.141 kg/ha) and the Southwestern (15.125 kg/ha) agro-ecological zones. The growth rate of *B. vulgaris* after three years was found to be similar to the outstanding growth rate mentioned in the literature. The growth performance of *B. vulgaris* was notably better in the L. Victoria crescent compared to the West Nile and Southwestern highlands – suggesting that efforts to promote the growing of *B. vulgaris* should prioritize the L. Victoria crescent agro-ecological zone. Overall, this study provides valuable information on the growth performance of *B. vulgaris* in different agro-ecological zones in Uganda. This information can be used to guide the promotion and development of bamboo farming in the country, which has the potential to improve livelihoods and contribute to sustainable development.

Article DOI: https://doi.org/10.37284/eajfa.7.1.1802

**APA CITATION**

Kalanzi, F., Kiyingi, I., Mwanja, C. K., Agaba, H., Malinga, M., Reza, S. & Jayaraman, D. (2024). Morphological Characteristics and Growth Performance of Bambusa vulgaris Schrad. Ex J. C. Wendl in Selected Agro-Ecologies of Uganda *East African Journal of Forestry and Agroforestry*, *7*(1), 76-86. https://doi.org/10.37284/eajfa.7.1.1802

**CHICAGO CITATION**

Kalanzi, Fred, Isaac Kiyingi, Christine Kalembe Mwanja, Hillary Agaba, Michael Malinga, Selim Reza and Durai Jayaraman. 2024. "Morphological Characteristics and Growth Performance of Bambusa vulgaris Schrad. Ex J. C. Wendl in Selected Agro-Ecologies of Uganda" *East African Journal of Forestry and Agroforestry* 7 (1), 76-86. https://doi.org/10.37284/eajfa.7.1.1802

**HARVARD CITATION**

Kalanzi, F., Kiyingi, I., Mwanja, C. K., Agaba, H., Malinga, M., Reza, S. & Jayaraman, D. (2024), "Morphological Characteristics and Growth Performance of Bambusa vulgaris Schrad. Ex J. C. Wendl in Selected Agro-Ecologies of Uganda", *East African Journal of Forestry and Agroforestry*, 7(1), pp. 76-86. doi: 10.37284/eajfa.7.1.1802.

**IEEE CITATION**

F., Kalanzi, I., Kiyingi, C. K., Mwanja, H., Agaba, M., Malinga, S., Reza & D., Jayaraman "Morphological Characteristics and Growth Performance of Bambusa vulgaris Schrad. Ex J. C. Wendl in Selected Agro-Ecologies of Uganda", *EAJFA*, vol. 7, no. 1, pp. 76-86, Mar. 2024.

**MLA CITATION**

Kalanzi, Fred, Isaac Kiyingi, Christine Kalembe Mwanja, Hillary Agaba, Michael Malinga, Selim Reza & Durai Jayaraman. "Morphological Characteristics and Growth Performance of Bambusa vulgaris Schrad. Ex J. C. Wendl in Selected Agro-Ecologies of Uganda". *East African Journal of Forestry and Agroforestry*, Vol. 7, no. 1, Mar. 2024, pp. 76-86, doi:10.37284/eajfa.7.1.1802

## INTRODUCTION

Bamboo has gained global recognition as an essential plant due to its unique characteristics of fast growth, ability to grow in varied environments, and potential to produce various commercial products that have the potential for job creation, livelihood improvement and environmental protection. Bamboo belongs to the family *Poaceae*, subfamily Bambusoideae, and has 128 genera. About 1718 bamboo species are distributed worldwide in tropical and subtropical regions (Canavan et al., 2017).

In Uganda, the number of bamboo species is quite low, as only two are native to the country. The two species are *Oldeania alpina* K. Schumach and *Oxytenanthera abyssinica* A. Rich, which are also referred to as highland and lowland bamboo. These species are found in natural stands within protected areas, covering an estimated area of 54,533 ha (Zhao et al., 2018).

Over the past few years, the Ugandan government has been focusing on the growth of the bamboo industry. Significant efforts have been put into encouraging the use of for social, ecological, and economic transformation. A national bamboo strategy has been developed for Uganda, which is committed to encouraging bamboo growth in the country. There is also a commitment to include bamboo as a species in restoring degraded forests. As a result, several bamboo species have been introduced into the country to diversify the genetic pool. Among the introduced bamboo species is *B. vulgaris* Schrad. ex J.C.Wendl - a dense clump-forming bamboo species native to southern China and Madagascar. Two cultivars of *B. vulgaris* can be distinguished in Uganda: plants with green culms (commonly known as green bamboo) and yellow culms with green stripes.

*B. vulgaris* is among the species that have been prioritized for bamboo industrialization in Uganda due to its fast growth, high biomass production, suitability for producing a wide variety of commercial products, and easy vegetative propagation through culm and branch cuttings (Banik, 2000; Zhu & Jin, 2018). However, the small raw material base remains a critical hindrance to its industrialization (Bahru & Ding, 2021; Mbaziira et al., 2018; Zhao et al., 2018).

The easy propagation and fast growth make *B. vulgaris* a candidate species for large-scale bamboo plantation development in the country. Research and development efforts on bamboo in Uganda have focused on the utilization and the basic inventory of existing bamboo stands

East African Journal of Forestry and Agroforestry, Volume 7, Issue 1, 2024
Article DOI: https://doi.org/10.37284/eajfa.7.1.1802

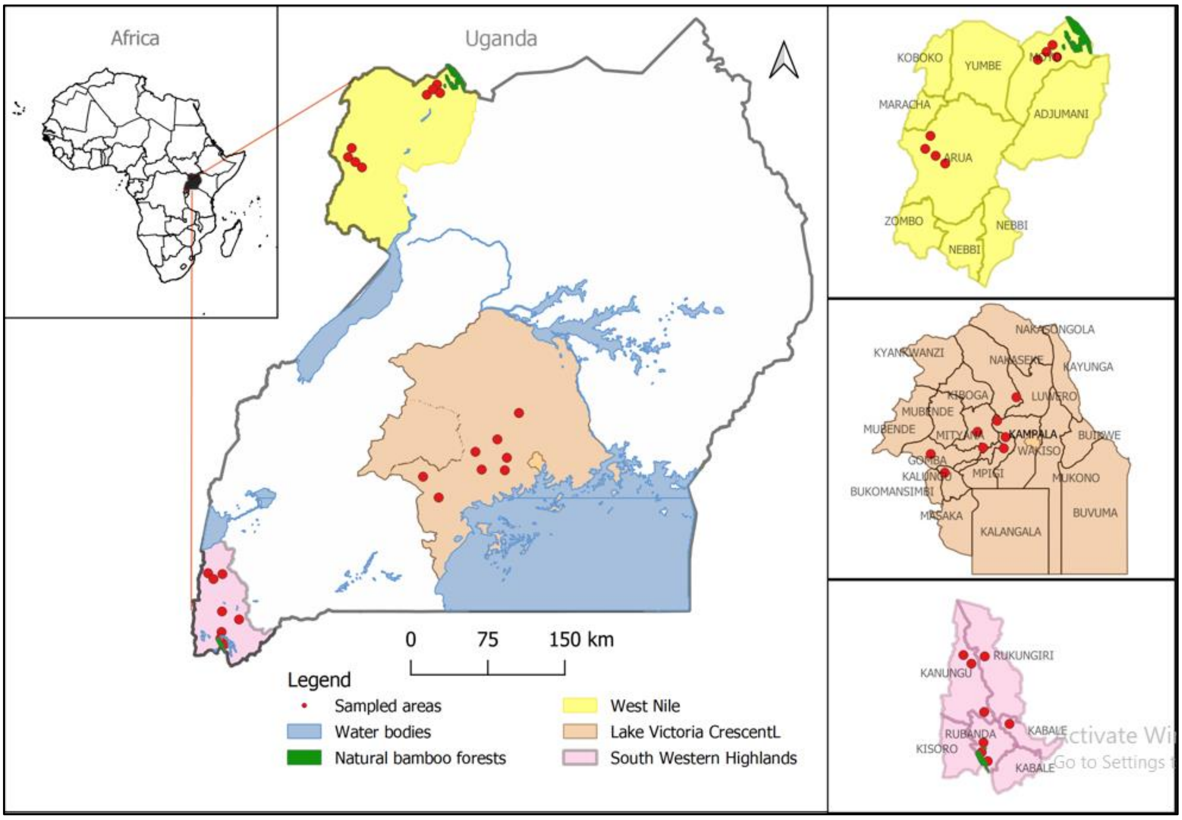
(Kalanzi et al., 2017; Mbaziira et al., 2018). However, more information is needed on the growth dynamics of individual bamboo species in different site conditions in Uganda (Nigatu et al., 2020). Such information is required to inform the large-scale promotion of bamboo for plantation development in Uganda. This study focused on *B. vulgaris* due to its high commercialization potential. The study aimed to describe the growth characteristics and determine the suitable sites for promoting the growing of *B. vulgaris* in Uganda.

## METHODOLOGY

### Study Area

Uganda is located on the Equator in the East African region. It covers a total area of 241,038 km$^2$, averages about 1,100 meters above sea level. It lies between latitude 1$^o$ 00' N and 32$^o$ 00' E. Uganda's geographical features comprise plateaus, highlands, mountains, rolling hills, flatlands, rivers, lakes, and wetlands. The climate of Uganda is generally tropical and rainy, with two distinct seasons from March to May and September to December. Uganda's soils are defined by various factors such as parent rock, rock age and climate, particularly the amount of moisture. The country is divided into nine agro-ecological zones based on agroclimatic factors (rainfall totals and distribution) and soils (productivity and fertility), influencing the growth of different plant communities. Topography, temperatures, moisture, and natural vegetation cover are the secondary factors considered uniform in each agro-ecological zone but differ between zones. The different agro-ecological conditions underlie the need to assess the growth performance before large-scale planting to avoid costly losses to farmers.

**Figure 1: Map of Uganda depicting various agro-ecological zones where the study was conducted**




The study was conducted in three agro-ecological zones of Uganda (Lake Victoria Crescent, West Nile, and Southwestern Highlands), which have been earmarked for restoration due to forest degradation in large parts of these areas. Bamboo is believed to play a significant role in forest restoration efforts in the above agro-ecological zones. The climatic conditions and soil types in each agro-ecological zone are summarised in *Table 1*.

Article DOI: https://doi.org/10.37284/eajfa.7.1.1802

**Table 1: Climatic conditions and soil types of the three agro-ecological zones**

| Agro-ecological zone | Altitude (AMSL) | Annual temperature (°C) | Annual rainfall (mm) | Soil type |
|---|---|---|---|---|
| Lake Victoria crescent | 1,000 – 1400 | 18 – 28 | Bimodal 1200 - 1450 | Sandy clay loams have medium to high productivity. |
| West Nile | 600 – 1,600 | 23 – 30 | Unimodal rainfall 1,500 – 1,700 | Sandy loam, acidic soils |
| Southwestern highlands | 1,000 – 3,500 | 10 – 25 | Bimodal 1250 – 1,500 | Volcanic |

**Source**: adapted from Wortmann and Eledu (1999).

**Sampling**

With the assistance of key informants, a record was compiled containing the names of 42 farmers who were provided with *B. vulgaris* seedlings by the National Forestry Authority and INBAR for planting across the three agro-ecological zones. The key informants were from the main stakeholders involved in promoting bamboo, including the National Forestry Authority, District Forest Officers, bamboo associations/ organizations, and companies. Key informants helped to establish the contact and specific location of bamboo farmers. To ensure a consistent and reliable dataset, rapid surveys were conducted with the farmers to obtain primary information about their bamboo cultivation practices, including the establishment time, planting pattern, and spacing. This screening process was done to identify farmers with relatively uniform bamboo stands, thereby controlling for variation in age, planting pattern and spacing - factors that could influence growth performance. As a result, out of the 42 farmers, 24 were found to have relatively uniform *B. vulgaris* stands were considered for data collection.

**Collection of Growth Performance Data**

*B. vulgaris* stands that were visibly unaffected by harvesting, fire, pests, and diseases were chosen for collecting growth performance data. The location of each bamboo stand was recorded using GPS and later used to enrich the map of the study area. The date of establishment of each bamboo stand was also noted down to estimate the age of bamboo clumps. In addition, sample plots of size 20m x 20m were temporarily created in each bamboo stand to measure growth parameters of *B. vulgaris*. Twenty-four temporary sample plots were established across the three agro-ecological zones using stratified sampling, with eight plots established in each agro-ecological zone. Morphological and phenological characteristics of *B. vulgaris* and the number of surviving bamboo clumps in each plot were recorded. Additionally, three bamboo clumps were randomly selected in each plot, and the parameters were measured as described in *Table 2*:

The study was conducted in September 2020. Due to the country's COVID-19 situation, all necessary precautions were taken to comply with the standard operating procedures (SOPs) implemented by the Ugandan government. To ensure that movement within and between districts was not hindered, clearance was obtained through the office of the Resident District Commissioner (RDC) in each district.

Article DOI: https://doi.org/10.37284/eajfa.7.1.1802

**Table 2: Parameters measured in each sample plot**

| Parameter | Description of parameter measurement |
|---|---|
| Clump circumference | The circumference of the clump was measured using a measuring tape and recorded in centimetres. |
| Number of culms | The total number of culms on each clump was counted and recorded according to three different age classes (Juvenile, 1-2 years, and above two years) (Table 3). The culm's age class was estimated based on culm colour, development of branches and leaves, and culm sheath. |
| Clump height | The height of the dominant culm (culm with the largest diameter) was measured for each of the three selected clumps in the plot. The culm was felled, and its length to the tip was measured and recorded as the clump height. The height of bamboo culms is a stable parameter as young plants reach their full height in 1-2 months (Yen, 2016) |
| Culm diameter and height | The diameter and height of each culm on the selected clump were measured. The diameter was measured at the base (10 cm above ground) and breast height (1.3 m) using a diameter tape, while the height was estimated using an altimeter. |
| Internode length and wall thickness | One culm in each age class was harvested from each clump using an arc saw and cross-cut into three equal parts to enable measurements of wall thickness using a ruler, internode length using a tape measure, and diameter using a diameter tape. |
| Morphological and phenology characters | Vegetative parts such as leaves, buds, branches, culms, culm sheaths, and internodes were observed and documented in their appearance. |

**Source:** Adapted from Hillary et al. (2022).

**Table 3: Distinguishing characteristics of *B. vulgaris* culms at different age classes**

| Age class | Distinguishing characteristics |
|---|---|
| Juvenile | Located on the outer sphere of the clump, it is pale green and visibly taller than the rest. There are no or few branches, and the culm sheath is still attached. |
| 1-2 years | Presence of branches; sheath tending towards detachment; usually located towards the centre of the clump; Slightly pale and Smooth surface |
| > 2 years | Sheath detached; usually located in the centre; small in diameter and rough, off-green surface |

**Source:** Adapted from Hillary et al. (2022).

**Data Analysis**

Correlation analysis was carried out to understand the strength and nature of the relationship between the growth parameters. Descriptive statistics were calculated for culm height, culm diameter, internode length, and the number of culms produced per clump, such as means, percentages, and minimum and maximum values. One-way Analysis of Variance (ANOVA) followed by Sidak post-hoc test was used to compare the performance of *B. vulgaris* across the different agro-ecological zones based on growth parameters.

*Biomass Stock Estimation*

The amount of biomass that each clump of *B. vulgaris* can accumulate was approximated using a method that doesn't require destroying the plant. This non-destructive method was preferred because it’s less expensive and time-saving. To estimate the above-ground biomass of individual culms (which includes the stem, branches, and leaves), a multi-species allometric equation developed by Xayalath et al. (2019) was utilized, represented as:

TAGB= 0.1794DBH2.2214

Where TAGB is the total above-ground biomass, and DBH is the diameter at breast height.

East African Journal of Forestry and Agroforestry, Volume 7, Issue 1, 2024
Article DOI: https://doi.org/10.37284/eajfa.7.1.1802

## RESULTS AND DISCUSSIONS

### Morphological Traits of *B. vulgaris*

This study considered 3-year-old *B. vulgaris* with green culms (*Plate 1*). Its culms were waxy when young, becoming smooth and shiny with age. The culms were hollow, inflexible, straight at the base, and slightly arching towards the top. The internodes were arranged in a zigzag pattern on the culm. Nodes were prominent, with the ones at the base bearing aerial roots. Its branching had an extra-vaginal pattern, with several primary branches emerging from the mid-culm nodes and one distinctively dominant.

**Plate 1: Distinguishing characteristics of *B. vulgaris* (green)**

The culm sheath was covered with dark brown hairs (*Figure 3*) and fell off at maturity (about three years). The culm sheaths were triangular, averaging 23.5 cm long and 2.5 cm wide. These dimensions of the culm sheath fall within the range of 15-40 cm and 2-5 cm in length and width, respectively, as Wahab et al. (2009) reported. The auricles on the culm sheath are relatively large, with small, rounded lobes, and its apex was slightly rounded at the blade. The leaf blades had a narrow oval shape, tapering to a point at each end (lanceolate). Shoots were conical, bulging slightly above the base before tapering towards the tip.

**Plate 2: Culm sheath for *B. vulgaris***

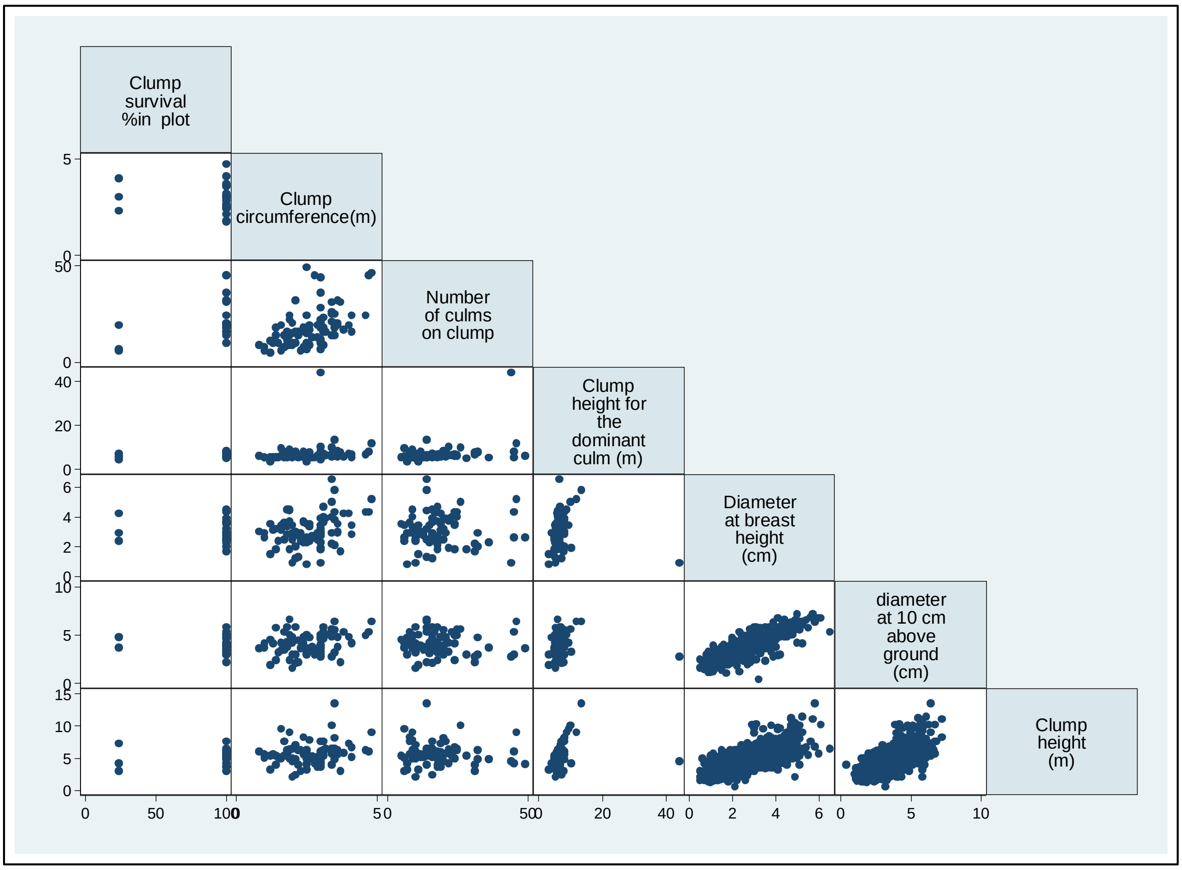
### Correlation between Growth Parameters

Results from the correlation analysis (*Figure 2*) showed a relatively strong positive correlation between diameter at 10 cm above ground and diameter at breast height. There was a moderately strong positive correlation between clump height and diameter at breast height, clump height and diameter at 10 cm above ground, and clump circumference and number of culms on the clump. There was no significant correlation between other parameters. The positive relationship between diameter at 10 cm above ground and diameter at breast height could be because both measurements are related to the overall size and growth of the culm. As the culm grows taller and broader, its diameter at 10 cm above ground and diameter at breast height also increases. There could be several reasons for the positive correlation between clump circumference and the number of culms on the clump. Firstly, a larger clump circumference could indicate a more extensive rhizome system, which could support the growth of more culms. Secondly, a larger clump circumference could provide more space for developing new culms, allowing the clump to support more culms. Our findings are consistent with earlier studies, which suggest that clump circumference may be a valuable indicator of culm productivity in bamboo stands (Liu et al. 2016; Zhang et al. 2018)

Article DOI: https://doi.org/10.37284/eajfa.7.1.1802

**Figure 2: Scatterplot matrix representing the correlation between growth parameters**




## Growth Performance of *B. vulgaris*

### *Clump and Culm Height and Diameter at Breast Height*

One-way ANOVA was conducted to compare the growth parameters of *B. vulgaris* (Table 4) at three years across three agro-ecological zones. The results (Table 4) showed significant differences in the clump height, culm height, and diameter at breast height across the three AEZs at a 5% significance level. Sidack posthoc test results revealed that the clump height of *B. vulgaris* in L. Victoria crescent (Mean = 6.72m, SD = 0.97) was statistically significantly higher than in the Southern highlands (Mean = 5.75m, SD = 0.76) at 5% significance level, but no significant difference in clump height between West Nile (Mean = 6.63m, SD = 0.78) and both L. Victoria crescent and Southern highlands AEZs. The culm height recorded in L. Victoria (Mean = 5.04m, SD = 1.0) and West Nile AEZs (Mean = 4.86m, SD = 1.4) was statistically significantly higher than for Southern highlands (Mean = 3.99m, SD = 1.45). Still, the culm height for L. Victoria was not significantly higher than for West Nile. The diameter at breast height in L. Victoria crescent (2.84 cm ± 1.0) was also significantly higher than in West Nile AEZ (2.57 cm ± 0.79) but not in Southern highlands (2.63cm ± 0.98). The DBH reported in this study is lower than the 17.9 - 26.75cm reported by Ojo and Sadiku (2023). The variations in the diameter could be a result of the age of the bamboo clump; the bamboo clumps in this study were only three years old and may not yet be mature enough to produce more giant culms.

### *Internode Length and Internode Diameter*

One-way ANOVA results (Table 4) also showed significant differences in the culm internode length and internode diameter across the three AEZs at a 5% significance level. Sidack post-hoc test results revealed that the culm internode length in the L. Victoria crescent (25.27cm ± 5.05) was significantly higher than in the West Nile (24.02 cm ± 4.17) and Southern Highlands (23.15 cm ± 4.54). The average internode length for culms from fully grown clumps is reported to be 25-45

Article DOI: https://doi.org/10.37284/eajfa.7.1.1802

cm (Antwi et al., 2022; Darwis & Iswanto, 2018; Gomes Neto et al., 2021). This study shows that when a clump is about three years old, the new culms that grow (referred to as juveniles) have an average internode length similar to the average length of *B. vulgaris* reported by Wahab et al. (2009). In addition to this, the internode diameter in the L. Victoria crescent (2.55 cm ± 1.22) was found to be significantly higher than in West Nile (measuring 2.29 cm ± 0.94) and Southern Highlands (measuring 2.31 cm ± 0.96). However, the internode diameter reported in this study was lower compared to the range of 3-9 cm reported by Antwi et al. (2022), Wahab et al. (2009) and Gomes Neto et al. (2021). This could be due to the underdevelopment of culms from a clump of three years old. Variations can also be due to environmental factors and elevation between the three agro-ecological zones. However, the culm wall thickness increased with age in all agro-ecological zones, which is consistent with previous studies that have reported a gradual thickening of the culm wall as the bamboo culm matures (Alvin & Murphy, 1988; Gritsch & Murphy, 2005; Lybeer et al., 2005). This is attributed to the deposition of lignin and other structural materials in the cell walls (Li et al., 2007). The mechanical properties of bamboo culms are closely related to the amount and distribution of lignin (Huang et al., 2022). These findings support the idea that progressive thickening of the culm wall is essential to bamboo maturation and contributes to its strength and durability. This is why mature bamboo culms are used for construction and other applications that require strength and durability.

The total above-ground biomass was highest in the L. Victoria crescent, followed by West Nile and southwestern agro-ecological zones. The TAGB values for the three AEZs reported in this study are comparable to those found for *B. vulgaris* in Ghana (16.91–37.65 kg) by Amoah et al. (2020). However, the TAGB from West Nile and South Western regions was lower than what was reported for *B. vulgaris* in tropical moist forests in Ghana (19-103 Mg/ha) by Adu-Poku et al. (2023), except for Lake Victoria Crescent. Our results from all three regions were lower than 77.22 kg/clump reported in 4-year *B. vulgaris* in Ethiopia (Alemayehu et al., 2015). This could be attributed to variations in the bamboo age, management practices and climatic conditions (Requena Suarez et al., 2021). Also, the bamboo clump has not yet reached the maximum vigour to produce high culm numbers at three years. Besides, the stem and leaf structures have not yet been fully developed to produce and store biomass optimally. The higher biomass in the L. Victoria Crescent could be attributed to the warm temperature and higher average annual rainfall of 1320mm. However, it ranges between 1750 mm and 2000 mm in many zone areas. The suitable temperature and adequate precipitation conditions of the L. Victoria crescent promoted *B. vulgaris* growth and increased its biomass accumulation.

Based on the analysis of clump height, dbh and total above-ground biomass per ha, *B. vulgaris* exhibited the highest performance in the L. Victoria crescent area, followed by West Nile and Southern Highlands regions. When compared to what has been reported in other studies (Abebe et al., 2021; Schneider et al., 2020), these results indicate that the growth performance of *B. vulgaris* at three years is impressive in all the three agro-ecological zones of Uganda. Therefore, it is recommended that *B. vulgaris* be promoted for growing in all three agro-ecological zones.

**Table 4: Means of *B. vulgaris* growth parameters across AEZs**

| Growth parameter | Agro-ecological zone | | | |
|---|---|---|---|---|
| | Southern highlands | L. Victoria crescent | West Nile | F value |
| Clump survival % in plot | 96 | 100 | 100 | 5.00 |
| Clump circumference (m) | 3.13±0.8 | 2.73± 0.85 | 3.02 ± 0.62 | 0.71 |
| Clump height (m) | 5.75±0.76 | 6.72±0.97 | 6.63 ± 0.78 | 4.39* |
| Culm diameter at breast height (cm) | 2.63±0.98 | 2.84± 1 | 2.57 ± 0.79 | 3.3* |
| Culm diameter at 10cm above ground (cm) | 3.65±1.08 | 3.61±1.1 | 3.39 ± 0.84 | 2.83 |
| Culm height (m) | 3.99±1.45 | 5.04± 1 | 4.86 ± 1.40 | 26.51* |
| Total above-ground biomass (kg/ha) | 15.125 ± 3.065 | 24.773 ± 5.665 | 17.471 ± 2.844 | |
| **Number of culms** | | | | |
| Juvenile | 5.25±2.63 | 6.87±2.90 | 6.63±3.54 | 0.77 |
| 1-2 years | 4.41±2.35 | 4.75±1.75 | 5.25±1.58 | |
| >2 years | 3.67±2.10 | 4.38±2.33 | 3.63±1.51 | |
| Overall | 13.41±6.09 | 16.44±5.81 | 15.2± 4.63 | |
| **Internode length(cm)** | | | | |
| Juvenile | 26.9±4.14 | 25.8±4.1 | 24.8±5.2 | 24.03* |
| 1-2 years | 25.2±3.7 | 24.1±3.3 | 23.6±3.2 | |
| > 2 years | 22.0±2.8 | 20.6±3.3 | 20.0±3.17 | |
| Overall | 25.27±5.05 | 24.02±4.17 | 23.15±4.54 | |
| **Internode Diameter(cm)** | | | | |
| Juvenile | 2.4±0.97 | 3.17±1.0 | 2.71±0.89 | 7.85* |
| 1-2 years | 2.48±1.04 | 2.5±0.97 | 2.3±0.86 | |
| > 2 years | 1.89±0.69 | 1.49±1.17 | 1.67±0.7 | |
| Overall | 2.31±0.96 | 2.55±1.22 | 2.29±0.94 | |
| **Culm wall thickness (cm)** | | | | |
| Juvenile | 0.50±0.12 | 0.60±0.12 | 0.60±0.09 | 0.04 |
| 1-2 years | 0.83±0.15 | 0.94±0.09 | 0.95±0.08 | |
| > 2 years | 1.35±0.21 | 2.02±0.95 | 1.55±0.08 | |
| Overall | 0.85±0.38 | 0.87±0.61 | 0.88±0.38 | |

** Significant at $p<0.05$*

## CONCLUSION AND RECOMMENDATION

At three years, *B. vulgaris* showed superior performance in the L. Victoria crescent compared to the West Nile and Southern Highlands, according to the measurements of growth parameters such as clump height, dbh, and total above-ground biomass. However, the results in all three agro-ecological zones are comparable to studies in other regions where *B. vulgaris* has been reported to perform well. Therefore, interventions should focus on promoting *B. vulgaris* in all three agro-ecological zones, particularly in the L. Victoria crescent. This study was based on bamboo stands that the farmers had established. The absence of scientifically established trials could have resulted in other confounding factors not examined in the study.

## ACKNOWLEDGEMENT

We acknowledge the financial support from the International Bamboo and Rattan Organisation (INBAR) for conducting this study and thank all the key informants and farmers who participated.

### Declaration of Competing Interests

The authors declare that they had no competing interests that could have influenced the work reported in this paper.

## REFERENCES

Abebe, S., Minale, A. S., Teketay, D., & Jayaraman, D. (2021). Biomass, Carbon Stock and Sequestration Potential of Oxytenanthera abyssinica forests in Lower Beles River Basin, Northwestern Ethiopia. https://doi.org/10.21203/rs.3.rs-251214/v1

Adu-Poku, A., Obeng, G. Y., Mensah, E., Kwaku, M., Acheampong, E. N., Duah-Gyamfi, A., & Adu-Bredu, S. (2023). Assessment of aboveground, belowground, and total biomass carbon storage potential of Bambusa vulgaris in a tropical moist forest in Ghana, West Africa. *Renewable Energy and Environmental Sustainability*, *8*, 3. https://doi.org/10.1051/rees/2023001

Alemayehu, A., Mulatu, Y., Eshete, N., & Terefe, M. (2015). *Growth performance and biomass accumulation of four introduced bamboo species in southwestern Ethiopia*. 10th World Bamboo Congress, Korea 2015. Retrieved from https://www.eefri.org/wp-content/uploads/2016/01/Growth-performance-and-biomass-of-introduced-bamboo-species…JA_.pdf

Alvin, K. L., & Murphy, R. J. [R. J.] (1988). Variation in Fibre and Parenchyma Wall Thickness in Culms of the Bamboo Sinobambusa Tootsik. *IAWA Bulletin N.S.*, *9*(4), 353–361. https://doi.org/10.1163/22941932-90001095

Amoah, M., Assan, F., & Dadzie, P. K. (2020). Aboveground biomass, carbon storage and fuel values of Bambusa vulgaris, Oxynanteria abbyssinica and Bambusa vulgaris var.vitata plantations in the Bobiri forest reserve of Ghana. *Journal of Sustainable Forestry*, *39*(2), 113– 136. https://doi.org/10.1080/105 49811.2019.1608452

Antwi, K., Adu, G., Adu, S., & Appiah-Yeboah, J. (2022). Physical and Fuel Properties of Bambusa vulgaris of Different Age Groups and Their Effect on Producing Biofuel. *South-East European Forestry: SEEFOR*, *13*(1), 53–64. https://doi.org/10.15177/seefor.22-05

Bahru, T., & Ding, Y. (2021). A Review on Bamboo Resource in the African Region: A Call for Special Focus and Action. *International Journal of Forestry Research*, *2021*, 1–23. https://doi.org/10.1155/2021/8835673

Canavan, S., Richardson, D. M., Visser, V., Le Roux, J. J., Vorontsova, M. S., & Wilson, J. R. U. (2017). The global distribution of bamboos: Assessing correlates of introduction and invasion. *AoB PLANTS.* Advance online publication. https://doi.org/10.1093/aobpla/plw078

Darwis, A., & Iswanto, A. H. (2018). Morphological Characteristics of Bambusa vulgaris and the Distribution and Shape of Vascular Bundles therein. *J. Korean Wood Sci. Technol.*, *46*(4), 315–322. https://doi.org/10.5658/WOOD.2018.46.4.315

Gritsch, C. S., & Murphy, R. J. [Richard J.] (2005). Ultrastructure of fibre and parenchyma cell walls during early stages of culm development in Dendrocalamus asper. *Annals of Botany*, *95*(4), 619–629. https://doi.org/10.1093/aob/mci068

Gomes Neto, J. A., Barbosa, N. P., Beraldo, A. L., & Melo, A. B. de (2021). Physical and mechanical properties of Bambusa vulgaris as construction material. Engenharia Agrícola, 41(2), 119–126. https://doi.org/10.1590/1809-4430-eng.agric.v41n2p119-126/2021

Hillary, A., Fred, K., Isaac, K., Christine, M., Michael, M., Theodros, G., ... & Durai, J. (2022). Bamboo Site–Species Matching Study in Uganda.

Kalanzi, F., Mwanja, C., Agaba, H., & Guuroh, R. T. (2017). Potential of bamboo as a source of household income in south western Uganda. *Journal of Bamboo and Rattan*, *16*(1), 33–45.

Li, X. B., Shupe, T. F., Peter, G. F., Hse, C. Y., & Eberhardt, T. L. (2007). Chemical changes with maturation of the bamboo species Phyllostachys pubescens. *Journal of Tropical Forest Science*, *19*(1), 6–12. Retrieved from https://www.jstor.org/stable/43594691

Lybeer, B., VanAcker, J., & Goetgherbeur, P. (2005). Variability in fibre and parenchyma cell walls of temperate and tropical bamboo culms of different ages. *Wood Sci. Technol.*, *40*, 477–492.

Mbaziira, A. M., Mubiru, S., Egunyu, D., O'Mahony, M. J., & Kalema, A. N. (2018). *Bamboo market value chain study*. Retrieved from International Bamboo and Rattan Organisation website: https://www.inbar.int/wp-content/uploads/2020/05/1527834301.pdf

Nigatu, A., Wondie, M., Alemu, A., Gebeyehu, D., & Workagegnehu, H. (2020). Productivity of highland bamboo (Yushania alpina ) across different plantation niches in West Amhara, Ethiopia. *Forest Science and Technology*, *16*(3), 116–122. https://doi.org/10.1080/21580103.2020.1791260

Ojo, A. R., & Sadiku, N. A. (2023). Slenderness coefficient and growth characteristics of Africa giant bamboo: Bambusa vulgaris Schrad. ex J.C. Wendl. *Advances in Bamboo Science*, *2*, 100017. https://doi.org/10.1016/j.bamboo.2023.100017

Requena Suarez, D., Rozendaal, D. M. A., Sy, V. de, Gibbs, D. A., Harris, N. L., Sexton, J. O., . . . Herold, M. (2021). Variation in aboveground biomass in forests and woodlands in Tanzania along gradients in environmental conditions and human use. *Environmental Research Letters*, *16*(4), 44014. https://doi.org/10.1088/1748-9326/abe960

Schneider, S. d. C. M., Molica, S. G., Ferreira, R. L. C., Gallo, R., Céspedes, G. H. G., Junior, F. T. A., & Santos, M. V. F. d. (2020). Biomass in commercial Bambusa vulgaris plantations under annual rotation in Northeast Brazil. *Scientia Forestalis*, *48*(125). https://doi.org/10.18671/scifor.v48n125.22

Wahab, R., Mohamed, A., Mustafa, M. T., & Hassan, A. (2009). Physical Characteristics and Anatomical Properties of Cultivated Bamboo (Bambusa vulgaris Schrad.) Culms. *Journal of Biological Sciences*, *9*(7), 753–759.

Wortmann, C. S., & Eledu, C. A. (1999). *Uganda's agro-ecological zones: A gide for planners and policy makers*. Kampala, Uganda. Retrieved from International Center for Tropical Agriculture website: http://ciat-library.ciat.cgiar.org/articulos_ciat/1999-Uganda_agroecological.pdf

Xayalath, S., Hirota, I., Tomita, S., & Nakagawa, M. (2019). Allometric equations for estimating the aboveground biomass of bamboos in northern Laos. *Journal of Forest Research*, *24*(2), 115–119. https://doi.org/10.1080/13416979.2019.1569749

Yen, T.-M. (2016). Culm height development, biomass accumulation and carbon storage in an initial growth stage for a fast-growing moso bamboo (Phyllostachy pubescens). *Botanical Studies*, *57*(1), 10. https://doi.org/10.1186/s40529-016-0126-x

Zhao, Y., Feng, D., Jayaraman, D., Belay, D., Sebrala, H., Ngugi, J., . . . Gong, P. (2018). Bamboo mapping of Ethiopia, Kenya and Uganda for the year 2016 using multi-temporal Landsat imagery. *International Journal of Applied Earth Observation and Geoinformation*, *66*, 116–125. https://doi.org/10.1016/j.jag.2017.11.008

Zhu, Z., & Jin, W. (2018). *Sustainable bamboo development*. Wallingford, Oxfordshire, UK: CABI.