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Technical Paper

Bamboo Site–Species Matching Study in Uganda

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About the International Bamboo and Rattan Organization

The International Bamboo and Rattan Organization (INBAR) is an intergovernmental organization dedicated to the promotion of bamboo and rattan for sustainable development. For more information, please visit www.inbar.int

About this Working Paper

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Foreword

The drive to slow down the extraction of woody forest resources in East Africa has provided countries with the opportunity to earnestly seek alternative sources of wood and related composite materials. Bamboo is fast emerging as one of the priority alternatives under consideration. It is a versatile resource with several documented uses such as timber substitute; in pulp and paper and in fiber and textile industries; as plastic composites, as food and beverage, for energy, in health, and in cosmetics. Further, it has a proven potential for soil erosion control, water recharge, and climate change mitigation and adaptation. Bamboo is considered to have the potential to contribute to flagship programs with a focus on small and medium scale enterprise (SME) development to promote manufacturing, the rehabilitation of degraded landscapes, employment creation, poverty reduction, economic development, and environmental resilience. In this regard, the Government of Uganda has considered bamboo as an essential natural resource to spur its use for environmental conservation and commercial use. Widespread adoption of bamboo is expected to significantly contribute to Uganda's commitments of increasing forest cover under its ten years bamboo development strategy, Bonn Challenge, AFR100, sustainable development goals (SDGs), the Convention on International Trade in Endangered Species (CITES), the Convention on Conservation of Biological Diversity (CBD), and the United Nations Framework Convention on Climate Change (UNFCC).

Currently, Uganda has low bamboo species diversity. Two indigenous species are *Oldeania alpina* (K. Schum.) (highland bamboo) and *Oxytenanthera abyssinica* (A. Rich) (lowland bamboo). These bamboo species mainly occur in natural stands in protected areas where they are estimated to cover an area of 54,533 ha (Zhao et al., 2018). In recent years, through the support of the International Bamboo and Rattan Organization (INBAR), efforts have been made to interest farmers and other stakeholders in bamboo cultivation. In 2019, the Uganda national bamboo strategy and action plan for 2019–2029 was launched to promote bamboo development in the country. Uganda aims to restore 375,000 hectares of degraded forest land with bamboo by the year 2030 (Ministry of Water and Environment, 2020). Although these efforts have been critical to the introduction of other bamboo species in the country, the introduction of exotic bamboo species has been uncoordinated; as a result, the area with the introduced bamboo species in Uganda is not easily identifiable, making it difficult to determine whether the species are planted in the appropriate agro-ecological zones (AEZs). This information gap has hampered the country's ability to estimate the existing bamboo resource base and its potential to contribute to environmental resilience and economic development.

This report on bamboo species' site suitability matching for Uganda is expected to identify the exotic bamboo species currently planted in the country and inform actors in the bamboo value chain about their growth performance and suitability for being planted in different AEZs. The report captures the origin of each bamboo species, its growth performance in its native range and in different AEZs where it is currently grown in Uganda, and its potential for ecological and socio-economic utilization in different parts of the country. This report is intended to serve as a guide for farmers, foresters, and extension agents in matching each bamboo species to its most suitable AEZ in Uganda. The guide is expected to provide the confidence needed by bamboo growers and value-chain actors in decision-making on bamboo production and utilization on a commercial scale.

Ali Mchumo

Director General, INBAR

List of Abbreviations

AEZs	Agro-ecological zones
AMSL	Above mean sea level
CFM	Collaborative forest management
CFR	Central forest reserve
cm	Centimeters
INBAR	International Bamboo and Rattan Organization
LG	Local government
M	Meters
mm	Millimeters
Mt	Mountain
MWE	Ministry of Water and Environment
NaFORRI	National Forestry Resources Research Institute
NARO	National Agricultural Research Organisation
NFA	National Forestry Authority
NWFP	Non-wood forest product
SMEs	Small and medium enterprises
UBA	Uganda Bamboo Association
UGX	Ugandan Shillings
UIRI	Uganda Industrial Research Institute
USD	United States Dollar
UWA	Uganda Wildlife Authority

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Executive Summary

Uganda's population continues to grow and so does the demand for fuelwood and wood products. Agriculture is also expanding into natural woodlands and forests. The resulting deforestation exacerbates climate change and its impacts. Further, forest plantations are failing to keep pace with the demand for wood and wood products. One promising option to arrest this challenge is to grow bamboo. Bamboo is fast-growing and can be selectively harvested over a long period. Bamboo is not new to Uganda, and although most of the bamboo resource is in protected areas, adjacent communities have already explored its use for food, construction, craft materials, fuelwood, and other utilizations.

Realizing the untapped potential of bamboo, Uganda has developed the National Bamboo Strategy (2019–2029) as a framework to support the development of the bamboo sector, allowing the private sector, both smallholder farmers and industrial plantation companies, to play a major role.

However, with the introduction of exotic bamboo species to diversify the genetic pool, guidance on which species to select for specific agro-climatic conditions and commercial utilization is limited. Knowledge and information on the growth performance of the different bamboo species introduced across the different agro-ecological zones (AEZs) in Uganda is insufficient. This knowledge is vital in prioritizing and promoting bamboo farming for environmental, social, and economic transformation.

This report thus presents findings of bamboo site–species suitability matching study for Uganda. In particular, this report validates the growth and performance of three-year-old plantations of *Bambusa vulgaris* and *O. abyssinica* and two-year-old plantations of *Dendrocalamus asper* and *Bambusa polymorpha*. Although the aim was to collect and present the growth performance data on other bamboo species as well, such as *O. alpina*, *Dendrocalamus membranaceous*, and *Dendrocalamus giganteus*, only a few scattered clumps on farmers' fields were encountered during the field data collection.

Both secondary and primary data were collected for this study. Secondary data were collected through a review of published and unpublished literature on bamboo. Primary data were collected through semi-structured interviews with key informants from the National Forestry Authority (NFA), INBAR, District Forest Officers, bamboo associations/organizations,

companies, and bamboo farmers. Growth performance data were collected by establishing temporary sample plots (20 m × 20 m) in each bamboo stand to measure growth parameters, including clump circumference, number of culms, clump height, culm diameter, internode length, and wall thickness. Morphological and phenological characteristics of each species were also recorded.

Based on the growth parameter (clump height, diameter at breast height, and total above-ground biomass per hectare) measurements, the growth performance of *B. vulgaris* at three years in the three AEZs (Lake Victoria crescent, West Nile, and Southern Highlands) was comparable to that reported elsewhere. *B. vulgaris* should therefore be promoted in all three AEZs. *B. polymorpha* performed significantly better in L. Victoria than in West Nile and should therefore be promoted in the L. Victoria crescent. The growth performance of *O. abyssinica* in both West Nile and the Southern Drylands was comparable to that observed in the mature plantations of Ethiopia. This implies that *O. abyssinica* can be promoted for cultivation in both AEZs. The growth performance of two-year-old *D. asper* in both the L. Victoria crescent and West Nile was comparable to the known growth performance in literature and therefore should be promoted in both AEZs.

The COVID-19 pandemic presented a great challenge to this study, as the team could not conduct group discussions and make timely visits to various locations. Other limitations included the uneven distribution of bamboo species in all the AEZs. This limited the data collection and comparison to only a few AEZs where sufficient data for given species could be established. In addition, other factors such as source of planting material and management regimes could not be controlled; accordingly, this variation could not be accounted for in the growth performance observed.

In a nutshell, the mentioned bamboo species will be considered in different agro-climatic zones in Ugandan context for environmental management, livelihood promotion, and industrial utility.

1. Background

1.1. African bamboo sector

Seven percent of the global bamboo resource lies in the African region, with total area coverage of over 2.8 million ha in six nations. Among these, Ethiopia has 31.55% of the entire bamboo resource, followed by Senegal (14.49%) and Ghana (8.77%) (Bahru and Ding, 2021). A total of 115 bamboo species are widely distributed among 48 countries in the African region, accounting for 7.3% of the global total (Bahru and Ding, 2021) in terms of species diversity and area coverage. *O. abyssinica*, distributed in 38 African countries, is the most widely distributed indigenous bamboo species. *B. vulgaris* is widely distributed among 20 African countries as an introduced bamboo species, followed by *D. giganteus* in 10 African countries. *D. asper* and *D. strictus* are each found in equal numbers in six African countries.

Despite the long history of bamboo resources in the African region, bamboo is widely used mainly for traditional applications such as housing, fencing, basketry, agricultural utilities, furniture, and fuelwood. The only country with much progress in terms of processing and utilizing bamboo in Africa is Ethiopia (Huojin, 2014). Based on the United Nations (UN) ComTrade database for reporting years 2014, 2015, and 2016, the African continent imports bamboo products valued at USD 21 million and exports valued at USD 18 million, representing 1.6% and 1.2% of the global imports and exports, respectively. With the global bamboo market rapidly growing, African governments and the private sector have begun positioning themselves to commercialize bamboo. The profit potential has become even more significant as environmentalists link bamboo with climate change mitigation and the possibility of increased income through carbon credits.

1.2. Ugandan bamboo sector

Uganda has low bamboo species diversity. The two dominating indigenous species are *O. alpina* K. Schum (highland bamboo) and *O. abyssinica* A. Rich (lowland bamboo). These bamboo species mainly occur in natural stands in protected areas, where they are estimated to cover an area of 54,533 ha (Zhao et al., 2018). The lowland bamboo (*O. abyssinica*) is found in Northern Uganda and West Nile, mainly in Otzi Mountains, Metu, and the Agoro-Agu Central Forest Reserve in the southern part of Imatong Mountains. Situated in the Moyo district of northern Uganda, the Otzi Mountains is an important water catchment situated in a relatively low precipitation area with a long dry season. The terrain is rugged, with an elevation range from 700 to 1600 m. The Otzi Forest Reserve is famous for its rich biodiversity. There has been evidence of the presence of chimpanzees; it is also well-known for the White Rhino Sanctuary (Ayebare, Nangendo and Nampindo, 2020). The Otzi Forest Reserve is covered by woody savanna, and the bamboo stands are usually mixed with thickets and bushes. The total area where bamboo grows is 87.74 km^2 in Otzi Mountains and Metu (Zhao et al., 2018). The Agoro-Agu Central Forest Reserve is located at the border between Uganda and South Sudan. The vegetation of this area includes Afromontane forests, shrublands, woody grasslands, and bamboo. Bamboo is widely distributed on the slopes between an elevation of 1170 and 1905 m, covering an area of 20.40 km^2 (Zhao et al., 2018).

Highland bamboo (*O. alpina*) naturally occurs on Mt. Elgon, on the Rwenzori Mountains, at the Mgahinga Gorilla National Park, and in the Echuya Central Forest Reserve (CFR). Mount Elgon is a giant, extinct volcano bordering Uganda and Kenya. Its vegetation belts include savanna woodlands and croplands, montane forests, bamboo, and moorlands from the bottom to the top. The bamboo belt covers 342.01 km^2 in total on both sides of Mt. Elgon, starting at an elevation of 2500 m, whereas it is less dense and restricted in patches above 2700 m (Zhao et al., 2018).

The Rwenzori Mountains, located in the equatorial zone, border Uganda and the Democratic Republic of the Congo. These mountains have different vegetation zones, including tropical rainforests, bamboo, montane cloud forests, heathlands, afro-alpine plants, bare rocks, and snow. The bamboo layer is between the two forest layers, at an elevation of 2625–3406 m, with an estimated overall area of 191.00 km^2 (Zhao et al., 2018).

The Mgahinga Gorilla National Park is situated in the south and west part of Uganda. It includes three of the eight Virunga Mountain volcanoes: Mt. Sabyinyo, Mt. Gahinga, and Mt. Muhabura. The park is a habitat for mountain gorillas and other endangered animals. The vegetation zones in the park include woodlands and a few montane forests at the base, bamboo in the middle, and the Afro-Alpine zone of grasslands and shrublands at the top. The bamboo belts for the three volcanoes are all at an elevation of 2700–3100 m, covering a total area of 8.66 km^2 (Zhao et al., 2018). Echuya is a natural forest reserve also located in southwestern Uganda. The forest reserve comprises different land cover types of pure bamboo, mosaics of bamboo and rainforests, pristine rainforests, and swamps. Bamboo is found along the upper slope of the eastern side, covering 1.04 km^2 (Zhao et al., 2018).

Since 2016, the INBAR has been implementing the Dutch-Sino East Africa Bamboo Development Programme in efforts to stimulate farmers' and other stakeholders' interest in bamboo growing in Uganda. In 2019, the Uganda National Bamboo Strategy and Action Plan for 2019–2029 were launched to promote bamboo development in the country. Uganda aims to restore 375,000 ha of degraded forest land with bamboo by the year 2030 (Ministry of Water and Environment, 2020). These efforts have been critical to the introduction of other bamboo species in the country. The exotic species, *B. vulgaris*, is naturalized and the most successfully cultivated bamboo species in Uganda. *B. vulgaris* is easily propagated through vegetative propagation methods and therefore is the most common bamboo species in most nurseries across the country. In addition, *Phyllostachys aurea* is a bamboo species common in urban areas and used for landscape modeling. Other bamboo species have been recently introduced, such as *Bambusa balcooa* Roxb., *D. asper* (Schult.) Backer, *B. polymorpha* Munro., *Dendrocalamus membranaceus* Munro., *D. giganteus* Munro., *D. strictus* (Roxb.) Nees, *Bambusa bambos* (L.) Voss, and *Dendrocalamus longispathus* Kurz. Many nurseries have taken up bamboo multiplication to respond to the growing demand for planting material in the country. It remains to be seen whether these species will adapt well to Ugandan conditions and be embraced by farmers. Some private enterprises operating bamboo nurseries include Friends of Bamboo, Talent Agroforestry, Uganda Bamboo Association, Chloroplast, Nile Ply, B4G, Erthmx Enterprises, Tree Trends and Devine Bamboo.

Owing to the limited availability of bamboo industries in Uganda that would use the resource, most of the bamboo utilization is still confined to the communities adjacent to the bamboo resources. Bamboo product development is mainly based on traditional practices, targeting subsistence needs and local markets, which often do not demand high-value products. The communities adjacent to bamboo resources access bamboo either informally or through some collaborative arrangement with the protected area authorities. Bamboo is of great socio-cultural and economic importance to the local people. The communities around Mt. Elgon (mainly the Gisu tribe) harvest young bamboo shoots, locally called “malewa” from highland bamboo, which is a local delicacy (Buyinza, 2009), whereas in other regions with similar bamboo species, bamboo shoots are not harvested for food. In southwestern Uganda, communities use highland bamboo for a wide range of applications, including fencing, firewood, staking, construction, and developing products such as beehives, baskets, and handcrafts (Kalanzi et al., 2017). In northern Uganda, lowland bamboo is mainly harvested to be used as poles for building material and for baskets and low-value furniture production.

Because most bamboo products are confined to the highly informal local markets, data collection on bamboo production, consumption, and export is challenging. Much of the bamboo used in households is not reflected in the formal economy. The data on exports of raw bamboo and edible bamboo shoots across borders remain largely undocumented. According to the UN ComTrade database of 2014–2016, the annual trade value of bamboo from Uganda stood at USD 304,000 for import and USD 203,672 for export—indicating that Uganda is still a negligible player in international bamboo trade. Several bamboo farmers are unaware of the prevailing market potential of bamboo. The COVID-19 pandemic has ushered in a significant degree of market sluggishness attributed to nationwide lockdowns, which have disrupted bamboo related activities.

Table 1. Brief description of bamboo species in Uganda

Species	***Origin***	***Ideal altitude range (AMSL)***	***Year of introduction***	***Responsible agency***	***Known uses worldwide***
Oxytenanthera abyssinica (A. Rich.) Munro (Lowland bamboo)	Native	1000–1800m			Construction, furniture, basketry and handicrafts, props, and agricultural implements. Shoots are edible. Leaves are extensively used as fodder. Suitable for biomass, charcoal, and energy.
Oldeania alpina (K. Schum.) (Highland bamboo)	Native	2200–3500m			Bamboo flooring tiles, timber, handicrafts, furniture, bamboo stick–based products, bamboo sliver–based products such as mats and bamboo mat boards, bamboo shoots, etc.
Bambusa vulgaris	Naturalized	0–1500 m			Basketry and handicrafts; fencing and low-cost application. High biomass production capacity; suitable for energy (charcoal and biomass).

Bambusa lako Widjaja (Black bamboo)	Indonesia				Ornamental
Cephalostachyum pergracile		500–1200 m			Bamboo stick– and silver–based product line and bamboo shoots.
Dendrocalamus giganteus	China	0–1200 m	2010	Unknown	Construction, handicrafts, furniture, and industrial panel products. Leaves are good fodder. High biomass production capacity (charcoal and energy).
Dendrocalamus strictus	China	0–1200 m	2017	Onvirons Farms	Furniture, construction, and basketry products; shoots are edible. Good fodder. Highly suitable for charcoal and energy applications.
Bambusa bambos (L.) Voss.	China	0–1500	2018	Onvirons Farms	Construction, furniture, and basketry; shoots are edible. Ideal for windbreaks and boundary fencing (spiny).
Bambusa nutans Wallich ex. Munro	China	600–1500 m	2019	INBAR	Construction, furniture, and basketry.
Dendrocalamus longispathus	China and India	-	2019	INBAR	Crafts and flute-making. Pulping, construction, laminated and plywood boards, charcoal, and biofuel.
Dendrocalamus hamiltonii Nees & Arn ex. Munro	China	600–1500 m	2019	INBAR	Construction, handicrafts, and furniture. Excellent bamboo shoots. Leaves: good fodder.
Bambusa balcooa	China	0–1000 m	2019	INBAR	Construction, furniture, and basketry products. Edible shoots. Suitable for biomass, charcoal, and energy.

Bambusa polymorpha	China and India	0–1500 m	2017	INBAR	Bamboo stick–based products; mats, blinds, chopsticks, and handicrafts; edible shoots.
Phyllostarchys aurea Rivière	China	0–2000 m			Light construction, ornamental.
Gigantochloa aspera Kurz ex. Munro	China	0–1400	2019	INBAR	Construction timber, furniture.
Dendrocalamus membranaceus cv. Grandis		50–1150 m	2018	INBAR	Construction/pulp and paper, laminated boards, and bamboo shoots.
Fargesia yunnanensis Hsueh & T.P.Yi	China		2017	INBAR	Edible shoots, farm tools.
Dendrocalamus barbatus	China	300–1100 m	2018	INBAR	Craft, construction, ply boards, handicrafts, and furniture; edible shoots.
Dendrocalamus yunnanensis	China	80–800 m	2019	INBAR	Bamboo shoots, construction, paper manufacture, and paper pulp and wood.
Dendrocalamus brandisii (Munro) Kurz	China	700–1500 m	2019	INBAR	Construction, furniture, farm implements, basketry, and handicrafts. Edible shoots. High biomass production capacity; suitable for energy.
Dendrocalamus asper (Schult. f.) Backer ex. Heyne	China	400–1500 m Thrives well at 400–500 m	2019	INBAR	Construction, furniture, basketry, and handicrafts; excellent shoots and fodder. Industrial panels. Products, chopsticks, and toothpicks.
Thyrsostachys oliveri Gamble	Thailand	500–700 m			Construction, furniture, props, farm implements, and tools. Suitable for farm boundary fencing and agro-forestry. Edible shoots.
Dendrocalamus hookeri Munro	China	700–1500 m	2019	INBAR	Construction, basketry,

					and panel-based products. Bamboo shoots. High biomass production; potentially suitable for energy.
Guadua angustifolia Kunth	China	500–1600 m	2019	INBAR	Construction and building material; furniture and handicrafts.

1.3. Rationale of the study

INBAR has supported bamboo initiatives among its Member States in Africa. Realizing the untapped potential of the bamboo sub-sector in East Africa, INBAR has since 2017 supported bamboo initiatives through the Dutch-Sino East Africa Bamboo Development Programme, covering Ethiopia, Kenya, and Uganda. The program applies the experiences and lessons learnt from hugely successful transformations of Asia's and Europe's bamboo market to East Africa to enable target countries to participate in and benefit from the bamboo economy. It aims at mainstreaming bamboo as a source of income and livelihood to create green jobs and upgrade the value chain.

In Phase I: Dutch-Sino East Africa Bamboo Development Programme, INBAR has made efforts to adapt indigenous (*O. abyssinica*) and naturalized (*B. vulgaris*) bamboo species to different AEZs of Uganda. In addition, INBAR introduced exotic bamboo species (such as *D. asper*, *Dendrocalamus membranaceus cv. grandis*, *B. polymorpha*, *Dendrocalamus barbatus*, *D. asper*, *Dendrocalamus hamiltonii*, *Fargesia yunnanensis*, and *Cephalostachyum pergracile*) to diversify the genetic pool of bamboo resources in Uganda. The first phase also led to the development of the National Bamboo Strategy for Uganda as a framework to support the development of the bamboo sub-sector. The emerging small and medium enterprises (SMEs) have incentivized the farmers in Uganda to cultivate bamboo in the homestead farming system and on private lands. Overall, this has led to increased interest among farmers and public and private organizations in planting bamboo for environmental and socio-economic benefits. However, with more bamboo species, guidance is limited on which species to select for specific agro-climatic conditions and end uses. Knowledge and information on the growth performance of the different bamboo species across the different AEZs in Uganda is limited. This knowledge is vital in prioritizing and promoting bamboo farming for environmental, social, and economic transformation. INBAR contracted the National Forestry Resources

Research Institute (NaFORRI) to conduct a bamboo site–species suitability matching study for Uganda. The following are the purposes of the study:

- To validate the growth and performance of indigenous and introduced bamboo species both in theory and practice;
- Shortlist and provide recommendations for the expansion of selected species for different agro-climatic clusters and end uses.

2. Methodology

2.1. Study area

The study was conducted in five out of the nine AEZs of Uganda where bamboo resources are growing in forest and non-forest (private) lands. The five zones were L. Victoria crescent, Southern Drylands, West Nile, Southern Highlands, and the Eastern Highlands. The five AEZs were selected based on a list of farmers who received bamboo seedlings for planting; the list was generated from the key informants (INBAR, NFA, and private nurseries supported by INBAR). Attributes of each AEZ are summarized in Table 1. Owing to the absence of scientifically designed trials, farmers' stands were adapted as trials while controlling for age and spacing: two factors that could cause variations in growth performance. Primary data on growth performance were collected on four bamboo species (*O. abyssinica*, *B. vulgaris*, *D. asper*, and *B. polymorpha*). These are the only species for which adequate data for site–species matching could be collected. Although other species were mentioned in the key informant interviews, some could not be found in the field, whereas others had only a few clumps that could not provide adequate data for analysis.

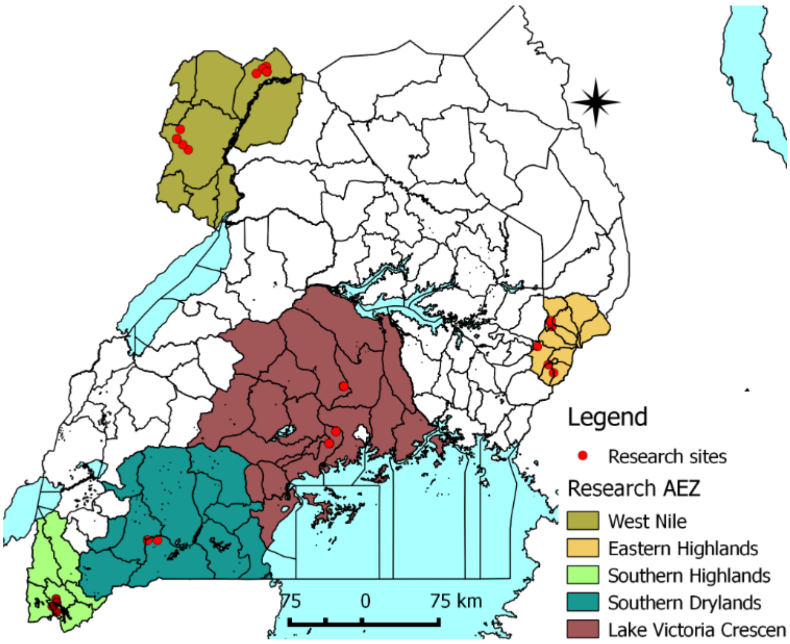

Figure 1. Map of Uganda showing the research sites in different AEZs (Source: own elaboration based on GPS points taken during fieldwork)

Table 2. Climatic conditions and soil types of the five study sites

Agro-ecological zone	*Altitude (AMSL)*	*Annual temperature (°C)*	*Annual rainfall (mm)*	*Soil type*
Lake Victoria crescent	1,000–1,400	18–28	Bimodal 1,200–1,450	Sandy clay loams with medium to high productivity.
West Nile	600–1,600	23–30	Unimodal rainfall 1,500–1,700	Sandy loam, acidic soils
Southern Drylands			<900	Sandy clay
Southwestern Highlands	1,000–3,500	10–25	Bimodal 1,250–1,500	Volcanic
Eastern Highlands	1,000–4,320	22–25	Bimodal 1,250–1,800	Volcanic

Source: Adapted from Wortmann and Eledu (1999).

2.2. Data collection

Secondary data were collected through a review of published and unpublished documents on bamboo. These data were used to compare our findings with earlier studies on the growth performance and characteristics of the species in their native range.

Key informants from NFA, District Forest Officers, bamboo associations/organizations, companies, and bamboo farmers were interviewed using a semi-structured questionnaire (Appendix I). Data from key informants were used to identify the specific location of bamboo farmers and the type of species they had planted. Data from farm owners included the type of bamboo species planted, the number of seedlings planted for each species, the year of planting, and the management operations undertaken on the bamboo stand. In addition, data were collected on the bamboo products shortlisted by bamboo enterprises. Owing to the COVID-19 restrictions in the country, the research team could not conduct focus group discussions and workshops as a means of data collection. All data were collected while complying with the standard operating procedures (SOPs) put in place by the government of Uganda. To ensure uninterrupted movement within and between districts, clearance was sought through the office of the Resident District Commissioner (RDC) in each district. The type and number of people interviewed were key informants (12), bamboo farmers (42), artisans or small enterprises (18), and traders (5).

Collection of growth performance data: A stand visibly unaffected by harvesting, fire, or pests and diseases was selected for collecting species-specific growth performance data. Global Positioning System (GPS) readings were recorded for each bamboo stand and later used to map the distribution of the bamboo plantation. The date of establishment of the bamboo stand was recorded and used to estimate the age of the bamboo clumps. Temporary sample plots (20 m × 20 m) were established in each bamboo stand to measure growth parameters. A total of 58 temporary sample plots were established across the five AEZs and included *B. vulgaris* (24), *D. asper* (12), *O. abyssinica* (10), and *B. polymorpha* (12). In each plot, we recorded the number of surviving bamboo plants/clumps. We then randomly selected three clumps to measure the different growth parameters, including clump circumference, number of culms, clump height, culm diameter, internode length, and wall thickness. Morphological and phenological characteristics of each species were also recorded.

Clump circumference*:* The circumference of the clump was measured using a measuring tape and recorded in centimeters.

Number of culms: The total number of culms on each clump was recorded according to three different age classes (juvenile, 1–2 years, above 2 years) (Table 2). The culm's age class was estimated based on culm color, development of branches, leaves, and culm sheath.

Table 3. Distinguishing characteristics for the different age classes of bamboo

Age class	***Distinguishing characteristics***
Juvenile	Located on the outer sphere of the clump; visibly taller than the rest; absence of/few branches; culm sheath still attached
1–2 years	Presence of branches; sheath tending toward detachment; usually located toward the center of the clump; slightly pale and smooth surface
Above 2 years	Sheath detached; usually located in the center; small in diameter Pale and rough surface

Note: detachment of the sheath varies from species to species

Clump height: A dominant culm (culm with the largest diameter) was considered to measure the clump height for each of the three selected clumps in a plot. The culm was then felled, and its length from basal point to 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 within a few months.

Culm diameter and height: Each culm on the selected clump was measured for diameter and height. The diameter was measured at the basal point (10 cm above ground) and at breast height (1.3 m) for culms in each age class using a diameter tape. Height was estimated using an altimeter.

Internode length and wall thickness: From each clump, one culm in each age class was harvested with the help of an arc saw and 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, bud, branches, culms, culm sheaths, and internodes were observed, and their appearance was documented for each bamboo species.

2.3. Data analysis

2.3.1. Growth performance

Descriptive statistics including means, percentages, minimum, and maximum were computed for culm height, culm diameter, internode length, and the number of culms produced per clump. Analysis of variance (ANOVA) was used to compare the performance of individual bamboo species across AEZs based on their growth parameters.

2.3.2. Biomass stock estimation

The biomass accumulation per clump of bamboo species was estimated. Given the limited resources, the non-destructive method was used to estimate biomass, as it is cheaper and less time-consuming than the destructive method. Total above-ground biomass (TAGB) for individual culms (including stem, branches, and leaves) was computed based on the developed allometric equations (Table 3), as finding the specific biomass allometric equations for all bamboo species in this study is not feasible. The allometric equation for above-ground biomass accumulation (dry weight) was represented as TAGB = 0.1794DBH2.2214.

Table 4. Selected allometric equations for the estimation of total above-ground biomass

Source	***Genus/species/multi-species***	***Selected equation***
Xayalath et al. (2019)	Multi-species	TAGB = 0.1794DBH2.2214
Gurmessa et al. (2016)	*O. abyssinica*	TAGB = −1.392 + 0.234 × Height + 0.766 × DBH

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

3. Study findings

3.1. *Bambusa vulgaris* Schrad. ex. J.C.Wendl

3.1.1. Description of Bambusa vulgaris

B. vulgaris is a dense, clump-forming bamboo species native to southern China and Madagascar and has become naturalized in several regions of the world. At least two cultivars of *B. vulgaris* can be distinguished in Uganda: plants with green culms and plants with yellow culms and often with green stripes of different intensities. In the context of this study, we mainly considered three-year-old *B. vulgaris* with green culms (Figure 2). Its culms were waxy when young, becoming smooth and shiny with age. The culms were hollow, inflexible, straight at the base, and slightly arching toward the top. The internodes were arranged in a zigzag pattern on the culm. The culms averaged about 6.3 m in height, with a culm wall thickness of 2.7 cm and internode length of 23.6 cm at three years. However, studies elsewhere have shown that when the clump is fully established, culms can grow up to 10–20 m in height with a culm wall thickness of 4–10 cm and internode length of 25–45 cm (Wahab et al., 2009; Darwis and Iswanto, 2018). The values of the physical characteristics (culm height, internode length, and culm wall thickness) were slightly lower in the context of this study because, at three years, the clumps had not yet been fully established. Nodes were prominent, with the ones at the base bearing aerial roots. *B. vulgaris* had an extra-vaginal branching pattern. Several primary branches emerged from the mid-culm nodes with one being distinctively dominant.

Figure 2. Distinguishing characteristics of *Bambusa vulgaris* (green)

The culm sheaths were covered with black hair (Figure 3) that fell off at maturity. They were broadly triangular, averaging 23.5 cm in length and 2.5 cm in width. These dimensions of the culm sheath fall within the range of 15–40 cm and 2–5 cm of length and width, respectively, as reported by Wahab et al. (2009). The auricles on the culm sheath were relatively large, with small rounded lobes. 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 in shape, bulging slightly above the base before tapering toward the tip.

Figure 3. Culm sheath for *B. vulgaris*

3.1.2. Growth performance of Bambusa vulgaris

The results on the *B. vulgaris* (green) growth parameters at three years (Table 4) show no significant differences in the survival, clump circumference, the number of culms on a clump, and the basal diameter of culms across the three AEZs at 5% significance level. However, significant differences were noted in the clump height, culm height, and diameter at breast height (dbh) across the three AEZs. Clump height was highest in L. Victoria crescent (6.72 m), followed by West Nile (6.63 m) and Southern Highlands (5.75 m). The clump height of *B. vulgaris* in L. Victoria crescent was statistically significantly higher than that in the Southern Highlands ($p < .05$). The culm height recorded in the L. Victoria and West Nile AEZs was statistically significantly higher than that in the Southern Highlands. The dbh in L. Victoria (2.84 cm) was also significantly higher than that in the West Nile AEZ (2.57 cm) at a 5% significance level.

The recorded internode length was significantly higher in the Southern Highlands (25.27 cm) than in the L. Victoria crescent (24.02 cm) and West Nile (23.15 cm), whereas the internode diameter in the L. Victoria crescent (2.55 cm) was significantly higher than that in West Nile (2.29 cm) and the Southern Highlands (2.31 cm). Within the same AEZ, the internode length and internode diameter generally increased with age from the juvenile culms to culms above two years. This variation is possible because within the first years of establishment, the clump is generally gaining vigor, and it is expected to stabilize at about three years. In this study, note that at about three years of clump development, the emerging culms (juveniles) had an average internode length and diameter that fell within the average ranges reported for *B. vulgaris* by Wahab et al. (2009). However, the culm wall thickness increased with age in all AEZs. This finding is in line with other studies that have reported the progressive thickening of the culm wall as the culm matures (Alvin and Murphy, 1988; Lybeer, VanAcker and Goetgherbeur, 2005; Gritsch and Murphy, 2005).

Overall, considering clump height, dbh, and TAGB per hectare, the results suggest that *B. vulgaris* performed best in L. Victoria crescent, followed by West Nile and Southern Highlands. These results indicate that the growth performance of *B. vulgaris* at three years in each of the three AEZs of Uganda is comparable to that reported elsewhere (Abebe et al., 2021; Schneider et al., 2020). Therefore, *B. vulgaris* can be promoted for cultivation in the above AEZs.

Table 5. Growth performance of *Bambusa vulgaris* 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*
Diameter at breast height (cm)	2.63 ± 0.98	2.84 ± 1	2.57 ± 0.79	3.3*

Diameter at 10 cm 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*
Number of culms	13.41 ± 6.09	16.44 ± 5.81	15.2± 4.63	0.77
Internode length (cm)	25.27 ± 5.05	24.02 ± 4.17	23.15±4.54	24.03*
Internode diameter (cm)	2.31 ± 0.96	2.55 ± 1.22	2.29 ± 0.94	7.85*
Culm wall thickness (cm)	0.85 ± 0.38	0.87 ± 0.61	0.88 ± 0.38	0.04
Total above-ground biomass per hectare (kg)	15,125 ± 3,065	24,773 ± 5,665	17,471 ± 2,844	

* Significant at $p < .05$

3.2. *Dendrocalamus asper* Backer ex. K.Heyne

3.2.1. *Description of Dendrocalamus asper in Uganda*

D. asper, also known as dragon or giant rough bamboo, is native to southeast Asia. It has a short, thick rhizome from which densely tufted erect culms emerge. The culms were green in color but predominantly covered with golden-brown hair toward the base (Figure 3). The young shoots were brownish-black. At two years, the clump height and culm diameter were in the ranges of 5–12 m and 2–6 cm, respectively. These ranges, however, are lower than those reported for well-established mature clumps. For instance, under favorable conditions, *D. asper* culms can attain a height of 18–25 m with a diameter of 12–18 cm (Aguinsatan et al., 2019; Midmore, 2006).

The nodes of *D. asper* were prominent with clusters of spikelets. The last three nodes at the base were found to be developing aerial roots. The average internode length was 28–35 cm, but the internode grows to 40–50 cm in well-established clumps (Srivaro and Jakranod, 2016). *D. asper* had an extra-vaginal branching pattern with one dominant central branch. The leaves were simple and alternated with lanceolate leaf-blades. The culm sheath (Figure 3) was large with no auricles. The upper surface was covered by golden-brown hair, whereas the area under the surface was smooth. Culm sheaths dropped off early.

Figure 4. Two-year-old *Dendrocalamus asper*

Figure 5. Culm sheath of *D. asper*

3.2.2. Growth performance of Dendrocalamus asper

The mean values of clump circumference, clump height, dbh, and number of culms on a clump of *D. asper* in the two AEZs were statistically significantly different, as determined by one-way ANOVA ($p < .05$) (Table 5). Sidak post-hoc tests revealed that clump circumference, clump height, dbh, and number of culms in a clump of *D. asper* in L. Victoria crescent were statistically significantly higher (at 5% significance level) than those in a clump of *D. asper* in West Nile by 1.3 m, 0.72 m, 0.43 cm, and 12.7, respectively. At 1–2 years, the internode length of *D. asper* in L. Victoria crescent was significantly higher than that in West Nile by 5.6 cm. Furthermore, significant differences were observed in measurements of the culm wall thickness of *D. asper* in the L. Victoria crescent and in West Nile. This follows Lybeer VanAcker, and Goetgherbeur (2005), who concluded that difference in location is responsible for differences in sample measurements.

These values of mean height, mean diameter, and TAGB per hectare are comparable to those recorded for the same species at two years in marginal sites of the Philippines (Fernandez et al., 2003). However, the average number of culms recorded in our study is much higher than that recorded for *D. asper* in the Philippines at two years. The higher number of culms in Uganda could be attributable to better site conditions than the marginal sites in the Philippines.

The relatively small diameters could be attributable to the high density of culms on the clump (Abebe et al., 2021).

Overall, based on the height, dbh, and TAGB per hectare, the growth performance of *D. asper* in L. Victoria crescent was much better than that in the West Nile AEZ. However, the growth performance of *D. asper* in the West Nile AEZ is still comparable with the known growth performance in literature at two years. Therefore, *D. asper* can be promoted for cultivation in both abovementioned AEZs.

Table 6. Growth performance of *Dendrocalamus asper*

Growth parameter	***Agro-ecological zone***		***F-value***
	L. Victoria crescent	West Nile	
Clump survival % in plot	100	100	
Clump circumference (m)	3.45 ± 0.6	2.08 ± 0.75	14.10*
No. of culms on clump	33.3 ± 10.5	20.66 ± 9.54	5.37*
Clump height (m)	11.76 ± 13.06	5.76 ± 1.61	1.22
Diameter at breast height (cm)	2.73 ± 0.88	2.29 ± 0.93	19.71*
Diameter at 10 cm above ground (cm)	3.5 ± 1.03	2.97 ± 1.06	
Culm height (m)	5.15 ± 1.36	4.44 ± 1.65	20.28*
Internode length (cm)	34.01 ± 7.55	30.84 ± 4.92	12.49*
Internode diameter (cm)	2.71 ± 1.94	2.61 ± 0.84	0.599
Culm wall thickness (cm)	1.79 ± 1.73	0.69 ± 0.37	7.17*
Total above-ground biomass per hectare (kg)	39,816 ± 9,373	17,867 ± 5,919	

3.3. *Oxytenanthera abyssinica* (A. Rich.) Munro

3.3.1. Description of Oxytenanthera abyssinica in Uganda

O. abyssinica is known as lowland bamboo. It is a bamboo species indigenous to Uganda. *O. abyssinica* is a sympodial (dense, clump-forming) bamboo. To control for age variation and ensure that adequate data are collected, our study focused on the three-year-old stands. In Uganda, the culms were pale green, erect, and leaned outward (Figure 6). The young shoots were gray-green and densely hairy. The culms were solid in older culms and semi-solid in young ones. An average height was 5–7 m, and the internode length was 13–25 cm. The values recorded for height and internode length in our study are higher than those reported by Terefe et al. (2016) in Ethiopia but fall within the range reported in other studies. According to Katende (1995) and Azene (1993), the mature *O. abyssinica* attains a height of 5–20 m and an internode length of 15–35 cm. The culms from three-year-old clumps had an average basal diameter of 3 cm, which is lower than the 10 cm diameter reported for culms from fully established clumps of *O. abyssinica* (Mulatu and Kindu, 2010). Several primary branches emerge from the mid-culm nodes, with one being distinctively dominant. The leaves were lanceolate, simple, alternate, and spiny—features similar to those reported by Azene (1993). The culm sheath, which was covered with dark-brown hair, ranged between 8 and 15 cm in length. The sheath had 2–5 mm long bristles at the top with a less prominent ligule. The blade of the sheath was linear-lanceolate and its base tapered into a short false petiole.

Figure 6. Three-year-old *Oxythenanthera abyssinica*

3.3.2. Growth performance of Oxytenanthera abyssinica

A statistically significant difference was observed in the clump height, culm height, and dbh of *O. abyssinica* in the two AEZs, as determined by the one-way ANOVA ($p < .05$) (Table 6). The mean clump height, culm height, and dbh of *O. abyssinica* in West Nile were statistically significantly higher (at 5% significance level) than those in the Southern Drylands AEZ by 1.43 m, 1.02 m, and 0.18 cm, respectively. A significant difference was also observed in the internode diameter and culm wall thickness of *O. abyssinica* between the West Nile and Southern Drylands AEZs. The clump survival in the two AEZs was 100%, which alludes to the favorable climatic conditions for *O. abyssinica*. *O. abyssinica* adapt to areas with low precipitation and high temperature (Katende, 1995; Fanshawe, 1972), typical of these AEZs.

Overall, based on height, dbh, and TAGB per hectare, *O. abyssinica* performed better in the West Nile than in the Southern Drylands. However, for both AEZs, the growth performance of *O. abyssinica* at three years is comparable to that observed in mature plantations in Ethiopia (Terefe et al., 2016; Darcha and Birhane, 2015). This implies that *O. abyssinica* can still be promoted in these two AEZs.

Table 7. Growth performance of *Oxytenanthera abyssinica*

Growth parameter	***Agro-ecological zone***		***F-value***
	West Nile	Southern Drylands	
Clump survival % in plot	100	100	
Clump circumference (m)	2.42 ± 0.58	2.65 ± 0.38	0.99
No. of culms on clump	14.44 ± 4.74	16.77 ± 6.05	0.83
Clump height (m)	6.86 ± 1.56	5.4 ± 0.957	5.49*
Diameter at breast height (cm)	2.12 ± 0.69	1.93 ± 0.53	6.07*
Diameter at 10 cm above ground (cm)	3.22 ± 0.94	3.19 ± 0.68	
Culm height (m)	4.74 ± 1.73	3.71 ± 1.38	29.63*
Internode diameter (cm)	6.11 ± 0.36	1.83 ± 0.72	77.36*
Internode length (cm)	23.13 ± 4.95	24.5 ± 5.54	13.73*
Total above-ground biomass per ha (kg)	12,166 ± 2,105	11,088 ± 1,339	

3.4. *Bambusa polymorpha* Munro

3.4.1. Description of Bambusa polymorpha in Uganda

B. polymorpha is an exotic sympodial bamboo species with dense clumping. Its culms were erect, curving outward at the top. The culms were light green when juvenile, turning to a grayish green color as they mature (Figure 7). Young shoots were greenish-brown in color. Distinct branching occurred from mid-culm to the top. The culms were occasionally solid near the base, with basal nodes having aerial roots. The culm height at two years was 5–7 m with a culm diameter of 2–4 cm. However, mature, well-established culms can grow up to 11–25 m in height with 7–15 cm diameter (Amlani et al., 2017). On average, culm internode length was 32–35 cm, which is lower than 86 cm reported by Amlani et al. (2017). *B. polymorpha* had several clustered branches with 1–3 larger dominant branches. Branches occurred from the middle of the culm to the top.

Figure 7. Two-year-old *Bambusa polymorpha*

Figure 8. Culm sheath of *B. polymorpha*

The culm sheath was thick and triangular, with a blade distinctly curved up toward the middle. The sheath did not fall off even on mature culms and was covered with white hair that turned dark brown. Its auricles were wavy and curled. The lower surface of the sheath was not hairy. The leaf blade was lanceolate.

3.4.2. Growth performance of Bambusa polymorpha

A statistically significant difference was observed in the mean values of clump circumference, culm height, dbh, and the number of culms in the clump of *B. polymorpha* in the different AEZs, as determined by one-way ANOVA ($p < .05$) (Table 7). Sidak post-hoc tests revealed that clump circumference, culm height, culm dbh, and the number of culms in the clump of *B. polymorpha* in L. Victoria crescent were statistically significantly higher (at 5% significance level) than those in the West Nile AEZ by 0.5 m, 0.8 m, 0.43 cm, and 13, respectively.

Based on the height, dbh, and TABG, *B. polymorpha* performed better in the L. Victoria crescent than in the West Nile and therefore should be promoted in the L. Victoria crescent.

Table 8. Growth performance of *Bambusa polymorpha*; summary of the findings

Growth parameter	***Agro-ecological zone***		***F-value***
	West Nile	L. Victoria crescent	
Clump survival % in plot	100	100	
Clump circumference (m)	1.33 ± 0.51	1.91 ± 0.41	5.82*
No. of culms on clump	9.66 ± 3.38	22.88 ± 11.28	7.60*

Clump height (m)	5.8 ± 0.7	6.38 ± 0.76	2.29
Diameter at breast height (cm)	1.96 ± 0.72	2.40 ± 0.82	13.51*
Diameter at 10 cm above ground (cm)	2.85 ± 0.92	3.58 ± 1.13	
Culm height (m)	3.69 ± 1.37	4.50 ± 1.1	21.31*
Wall thickness	0.57 ± 0.05	1.27 ± 0.23	23.85*
Internode length	32.5 ± 0.96	34.7 ± 8.57	3.54
Internode diameter	1.98 ± 0.86	2.52 ± 1.11	13.55*
Total above-ground biomass per ha (kg)	5,709 ± 1,135	20,194 ± 2,649	

3.5. Short- and medium-term bamboo products

Both small-scale bamboo farming and commercial plantations have only emerged in the country owing to improved awareness about the potential of bamboo for income generation. Until now, only few players are involved in bamboo farming. Most of the farmers do not intend to use bamboo for value addition; rather, they supply it to the bamboo industry and SMEs that they anticipate to emerge out of the ongoing initiatives by the government, non-governmental organizations, and donors.

Although few bamboo enterprises are emerging in the L. Victoria crescent because of the anticipated demand, bamboo product development hotspots remain in the West Nile, North, Eastern Highlands, and Southwestern Highlands—in areas adjacent to the naturally occurring bamboo resources. Communities in these areas have traditionally experimented with a range of bamboo products used domestically and traded in the local markets. A range of bamboo products and stakeholders that were found have been highlighted in Table 8.

Table 9. Bamboo products and stakeholders involved in product development

Agro-ecological zone	***Stakeholder***	***Products***	***Main bamboo species used***	***Comments***
Lake Victoria crescent	Uganda Industrial Research Institute (UIRI)	Toothpicks, furniture, mats	*O. alpina* *B. vulgaris* *D. giganteus*	UIRI is a government research and training institution mandated to promote industrial development through business incubation. They have the processing equipment that can be utilized to develop high-quality bamboo products.

	NaFORRI	Furniture, utensils, jewelry, treated poles, charcoal	*D. giganteus, B. vulgaris, D. strictus*	NaFORRI is a public research institute with a mandate to engage in forest research. They have a mature bamboo plantation where selective harvesting of culms is done for product development. They also have a bamboo nursery with the capacity to raise over 100,000 bamboo seedlings per annum.
	Talent Agro-Forestry Farm	Bamboo charcoal	*B. vulgaris*	Located in Nakaseke district, they also engage in capacity development, especially for youths and women, in different bamboo activities, including nursery operations. Their bamboo nursery can produce 10,000 seedlings.
	Devine Bamboo	Bamboo charcoal briquettes	*B. vulgaris, D. giganteus*	Located in Wakiso district
	Individual Artisans	Jewelry, flower pots, furniture, lampshades, amplifiers	*B. vulgaris, D. giganteus*	They mainly use hand tools in the processing.
West Nile	Artisans	Chairs, beds, stools, winnowing trays, baskets	*O. abyssinica*	Local community freely accesses bamboo from the Otzi Forest Reserve for production of the articles.
	Friends of Bamboo	Treated bamboo poles	*O. abyssinica*	Bamboo is mainly harvested from Metu forest, treated, and sold for construction. They have established their bamboo plantation.
Eastern Highlands	Bamboo shoot collectors and processors	Bamboo shoots	*O. alpina*	Bamboo shoots are collected from Mt. Elgon National Park both legally and illegally. The edible shoots are used for household consumption as well as for sale. Local communities collect bamboo shoots and sell to processors or direct to market (fresh) and may

				keep some for home consumption.
	AW Bamboo Enterprises	Bamboo shoots	*O. alpina*	Located in Mbale on Mbale-Tororo road, they process and package bamboo shoots.
Southwestern Highlands	Artisans	Baskets, trays, beehives.	*O. alpina*	Access bamboo culms from Echuya CFR through the collaborative forest management arrangement with the NFA
	Kisoro Bamboo Handicraft Cluster Cooperative Society	Trays, mats, vases, beds, tables, folders, spatulas	*O. alpina*	Members were trained in making various bamboo products by United Nations Industrial Development Organization (UNIDO) and Kenya Forestry Research Institute (KEFRI).

3.5.1. Lake Victoria crescent

Only few pockets of bamboo are mainly located on private farms. To most bamboo enterprises, the limited availability of bamboo raw material for product development remains the main challenge. The main products identified in the L. Victoria crescent are bamboo toothpicks, furniture, mats, jewelry, flower pots, and lampshades. The processing is still rudimentary, with most of the products lacking proper finishing. A significant bamboo market is anticipated if techniques for the processing of high-end products can be implemented.

Figure 9. Highlights of bamboo processing equipment and products at UIRI

3.5.2. Southwestern highlands

Kisoro and Kabale have several bamboo artisans. Most of them rely on indigenous knowledge to produce a range of products such as baskets, trays, and beehives. However, a few of them were trained by United Nations Industrial Development Organization (UNIDO) and organized into the Kisoro Bamboo Handcraft Cluster Cooperative Society. The cooperative comprises 118 people from 3 sub-counties (Kanaaba, Nyarusiza, and Muramba) who were trained to produce different bamboo products. The main challenge to commercializing bamboo in the region is that people still rely on the Echuya Central Forest Reserve to obtain bamboo raw materials. Access to the forest is highly restricted, and most of the time, bamboo is illegally extracted. Access to planting material is also a hindrance to those interested in domesticating.

Figure 10. Some of the bamboo baskets being produced in Kisoro and Kabale

3.5.3. West Nile

Residents exploit bamboo resources to obtain bamboo stems mainly used in construction. These stems are obtained from forest reserves such as Metu, Otzi, Ayipe, Atiya, and Ongom. Some artisans also produce baskets and chairs. People in the area still have limited interest in bamboo planting. Most of them rely on the naturally existing bamboo resources, which can be freely accessed.

Figure 11. Poles of *O. abyssinica* used for construction in Moyo, West Nile

3.5.4. Eastern highlands

The main marketable product from bamboo resources in the region was the bamboo shoots eaten as a vegetable and a delicacy among the Gisu tribe. The collection of bamboo shoots is seasonal (May–August) and permitted by the Uganda Wildlife Authority under the collaborative forest management arrangement. Bamboo shoots are collected and smoked in the field to reduce their weight and then directly sold to consumers in the village markets. A few entrepreneurs buy the raw shoots from the village markets and perform secondary processing to produce dried bamboo shoots (branded as malewa) that are sold in local supermarkets. Bamboo poles are also harvested from the forest and used for construction, handicrafts, and furniture.

Figure 12. Bamboo shoots processed and packaged as malewa

4. Conclusions and recommendations

Based on the growth parameter (clump height, dbh, and TAGB per hectare) measurements, the growth performance of *B. vulgaris* at three years in the three AEZs (L. Victoria crescent, West Nile, and Southern Highlands) was comparable to that reported elsewhere. *B. vulgaris* should therefore be promoted in all the three AEZs for land restoration, river bank protection, and commercial utilization as fuel. *B. polymorpha* performed significantly better in the L. Victoria crescent than in the West Nile and should therefore be promoted in the L. Victoria crescent. The growth performance of *O. abyssinica* in both West Nile and the Southern Drylands was comparable to that observed in the mature plantations of Ethiopia. This implies that *O. abyssinica* can be promoted for cultivation in both the AEZs. The growth performance of two-year-old *D. asper* in both the L. Victoria crescent and West Nile was comparable to its known growth performance in literature and therefore should be promoted in both AEZs.

This study has several limitations. The studied bamboo species were not evenly distributed in all the AEZs. This limited the comparison to only the AEZs where data were sufficient for a given species. In addition, many factors such as seedling source, time of establishment, and management regime (weeding, pruning, protection against grazing animals, and thinning) could not be controlled, which could have accounted for the differences in growth performance recorded. To improve the robustness of the results, future studies on site–species matching in Uganda should be guided by scientifically established and managed trials in all the AEZs.

The COVID-19 pandemic presented a great challenge to this study, as the team could not conduct group discussions and make timely visits to various areas.

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List of Appendices

Appendix 1: Tool for key informant interviews

Objectives:

- To identify key stakeholders in the bamboo sub-sector
- To be able to locate the bamboo farmers
- To identify the potential products produced from bamboo

Interview guide questions:

- What is your main role in the bamboo value chain?
- What are the species of the bamboo seedlings you distributed to farmers?
- What was the source of the seedlings you distributed?
- Describe the process that preceded the distribution of the seedlings.
- How was follow-up done to ensure that the seedlings were planted on time?
- Please provide the list and contact information of farmers/enterprises who received the seedlings.
- What do you think were their main motivations for planting bamboo?
- Please talk about the coordination and communication among bamboo stakeholders and how this impacted the bamboo sub-sector.
- What are the main challenges faced by bamboo farmers in your area?
- What recommendations do you have for improving bamboo farming in the country?

Appendix 2: Tool for farmer interviews and growth performance data collection

Farmer identification information

Agro-ecological zone	
District	
Subcounty	
Parish	
Village	
Name of the owner	
Date of data collection	

Section A: Bamboo species information and products

1. Source of planting material? (Tick appropriately)

1	**INBAR**	
2	NFA	
3	Private nursery (specify…)	

2. Bamboo species planted on the farm

	Species name	Area planted (acres)	Date of planting	Placement (1. boundary; 2. intercropped; 3. pure stand)	Planting pattern (random or systematic)	Spacing
1						
2						
3						
4						
5						

3. Why did you plant bamboo on your farm?
    1. For land rehabilitation
    2. To harvest poles for home use
    3. To harvest poles for sale
    4. Food (Malewa)
    5. To produce products
    6. Others; specify…………………..

4. Product information

Products currently produced from bamboo	**Products you intend to produce from bamboo in the short to medium term**
1. Untreated poles 2. Unprocessed bamboo shoots 3. Baskets 4. Furniture 5. Jewelry 6. Charcoal 7. Toothpicks 8. Floor panels 9. Mats 10. Treated bamboo poles 11. Tinned or packaged malewa	1. Untreated poles 2. Unprocessed bamboo shoots 3. Baskets 4. Furniture 5. Jewelry 6. Charcoal 7. Toothpicks 8. Floor panels 9. Mats 10. Treated bamboo poles 11. Tinned or packaged malewa

Section B: Growth performance data (based on a temporary sample plot of 20 m × 20 m for each species)

1. AEZ…………………………………
2. Species…………………………….
3. Number of clumps in plot……………….
4. Clump survival percentage in plot………………………………

Clump parameters				Culm parameters						
Clump no.	**Clump circumference (m)**	**Number of culms on clump**	**Clump height for the dominant culm**	**Culm no.**	**Diameter at breast height (cm)**	**Diameter at 10 cm above ground (cm)**	**Clump height (m)**	**Number of juveniles**	**Number (1–2 years)**	**Number (Above 2 years)**
				1						
				2						
				3						
				4						
				5						
				6						
				7						
				8						
				9						
				1						
				2						
				3						
				4						
				5						
				6						
				7						
				8						
				9						
				1						
				2						
				3						
				4						
				5						
				6						
				7						
				8						
				9						

Section C: Species identification
Clump characteristics

No.	Species	Density grade of the clump *1) Very dense, 2) Dense, 3) Scattered*	Clump habit *1) Erect, 2) Arching over, 3) Decumbent, 4) Scant, 5) Grassy*
1			
2			
3			
4			
5			
6			

Internode length and diameter across age groups
Species ……………………………….

Internode number	Juvenile						1–2 years						Above 2 years					
	Clump 1		**Clump 2**		**Clump 3**		**Clump 1**		**Clump 2**		**Clump 3**		**Clump 1**		**Clump 2**		**Clump 3**	
	L	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		
11																		
12																		
13																		

Wall thickness to diameter ratio
Species ……………………..

Clump	Age	Top			Middle			Bottom		
		Diameter (cm)	**Wall thickness (cm)**	**Ratio**	**Diameter (cm)**	**Wall thickness (cm)**	**Ratio**	**Diameter (cm)**	**Wall thickness (cm)**	**Ratio**
1	**Juvenile**									
	1–2 years									
	Above 2 years									
2	**Juvenile**									
	1–2 years									
	Above 2 years									
3	**Juvenile**									
	1–2 years									
	Above 2 years									

Rhizome characteristics

Parameter	Grade	Answer
Habit	1. Running over ground 2. Running underground 3. Specialized as props for culms	
Form	1. Pachymorph (dense clump habit) 2. Leptomorph (scattered clump habit)	
Lateral buds	1. Dome shaped 2. Boat shaped 3. Absent	
Axis growth	1. Determinate 2. Indeterminate	
Position of roots	1. At nodal rings 2. Throughout the surface	

Culm characteristics

Parameter	Grade	Answer
Origin	1. Distal to rhizome 2. Proximal to rhizome 3. Lateral to rhizome	
Color	1. Dark green 2. Green 3. Light green 4. Pale green 5. Striped	
Surface	1. Glabrous 2. Glaucous 3. Bristled 4. Spiny at nodes	
Shape of internode	1. Slender 2 Thicker near lower node 3. Streaked constrictions 4. Ridged surface	
Shape of node	1. Level nodal line 2. Dipping nodal line 3. Biannular nodal line	
Bud position	1. Above the node 2. On the node 3. Below the node	
Arrangement	1. All in one series 2. Alternate positions	
Number of nodal rings		
Number of nodal buds		
Bud size and shape		

Branching characteristics

Parameter		Grade	Answer
Origin		1. At nodal line 2. Above nodal line 3. From a specialized overgrowth	
Habit		1. Angled upwards 2. Level 3. Angled downwards 4. Appressed	
Development		1. Intravaginal 2. Extravaginal 3. Both	
Branching pattern		1. Single 2. Bunch of same size 3. Bunch with unequal branches 4. Tufted (Aspidate)	
Shape		1. Simple 2. Curved 3. Constriction at nodal points 4. Spiny and thorny	
	At upper half of culm	Primary	

Number of branches		Secondary	
		Tertiary	
	At lower half of culm	Primary	
		Secondary	
		Tertiary	
Length of branch (cm)	**At upper half of culm**	Primary	
		Secondary	
		Tertiary	
	At lower half of culm	Primary	
		Secondary	
		Tertiary	

Culm sheath characteristics

Parameter	Grade	Answer
Duration	1. Persistent 2. Caduceus 3. Deciduous	
Texture	1. Soft 2. Hard 3. Leathery	
Surface	1. Glaucous 2. Glabrous 3. Hairy 4. Spinules present	
Sheath blade posture	1. Erect 2. Horizontal 3. Reflexed	
Sheath blade, sheath joint ring	1. Bulged 2. Prominent 3. Inconspicuous	
Size of sheath blade (cm)	Length near node	
	Breadth near sheath blade	
	Shape	

Leaf characteristics

Parameter		Grade	Answer
Color	Dorsal	1. Dark green 2. Green 3. Pale green	
	Ventral	1. Light green 2. Whitish green 3. White due to powdery surface	
Texture		1. Leathery 2. Soft 3. Brittle	
Surface		1. Glaucous 2. Glabrous 3. Hairy	
Habit		1. Stiff 2. Flexuous 3. Erect 4. Pendant	
Venation		1. Prominent 2. Conspicuous 3. Inconspicuous	
Glands		1. Prominent 2. Minute 3. Inconspicuous	
Stalk		1. Long (above 1 cm) 2. Medium (0.5 cm) 3. Small (below 0.5 cm) 4. Absent (sessile)	
Sheath		1. Laminar 2. Spinose 3. Hairy	

	4. Ligulose 5. Absent	
Size (length × breadth) (cm)	Lower leaves	
	Upper leaves	

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