

Technical Paper

Bamboo Species-Site Matching Study in Ethiopia

**Agena A.¹, Berhane K.¹, Yigardu M.¹, Abera G.¹, Melkamu A.¹, Urgessa T.¹,
Solomon M.¹, Wondimagegn B.², Fiker A.², Theodros G.², Selim R.², Durai J.²**
2023

¹ Ethiopian Forestry Development

² International Bamboo and Rattan Organization



Ministry of Foreign Affairs of the
Netherlands



©International Bamboo and Rattan Organization 2022

This publication is licensed for use under Creative Commons Attribution-Non-Commercial-ShareAlike 3.0 Unported (CC BY-NC-SA 3.0).

To view this license, please visit <http://creativecommons.org/licenses/by-nc-sa/3.0/>.

About the International Bamboo and Rattan Organization

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

About this Working Paper

This work is an INBAR publication produced as part of the Dutch–Sino–East Africa Bamboo Development Programme (Phase II), which is funded by the Ministry of Foreign Affairs of the Kingdom of the Netherlands, as well as by the National Forestry and Grassland Administration of China. The program is a triangular South–South cooperation to support livelihood development, food security, and better environmental management by developing robust bamboo value chains and sustainable bamboo industries in Ethiopia, Kenya, and Uganda.

For more information, please visit <https://www.inbar.int/project/sino-east-africa-bamboo-development-programme-phase-ii/>.

International Bamboo and Rattan Organization

P.O. Box 100102-86, Beijing 100102, China Tel: +86 10 64706161; Fax: +86 10 6470 2166

Email: info@inbar.int

©International Bamboo and Rattan Organization 2023

www.inbar.int

Foreword

Bamboo and bamboo products hold significant potential to contribute to the sustainable development of Ethiopia, especially in building a green economy. Ethiopia is the primary grower of bamboo in Africa but is still far from achieving effective and efficient use of its bamboo resources. The country has adopted a ten-year bamboo strategy and action plan to enhance the development, utilization, and sustainable management of its bamboo resource. Through the introduction of a comprehensive strategy and action plan, it is envisaged that by the end of 2030, Ethiopia would have become the leading high-value bamboo producer and supplier in Africa.

Effectively managed and utilized bamboo resources will create efficiently integrated supply chains that would transform bamboo trade. It would enhance and develop the capacity of the Ethiopian people, from small-scale and traditional bamboo producers to large-scale modern industrial producers and exporters of bamboo products. These efforts would, in turn, increase the value of Ethiopia's bamboo products, improve degraded land, and contribute to achieving Ethiopia's landscape restoration targets, attract investment, increase Ethiopia's exports and reduce the volume of wood product imports, create decent jobs, and enhance Ethiopia's climate change adaptation and mitigation capabilities.

However, according to studies conducted by the International Bamboo and Rattan Organization (INBAR) in East Africa, the current bamboo resources in Ethiopia are not effectively managed, and the quality and quantity of the bamboo resources currently available at specific sites are insufficient to feed large-scale industries. Therefore, improving the management of existing natural and plantation bamboo forests, and establishing new model bamboo plantations in potentially favorable areas of the country, for high-quality bamboo culm production in sufficient quantities should get the attention and support of government and nongovernmental actors.

There are no guidelines with descriptions of the bamboo species in the country for ease of identification by bamboo growers and agriculture extension agents in the field. There is also a dearth of information among bamboo processors on the preferred uses of particular species. In addition, insufficient information on the growing conditions required for the various species is hindering expanding bamboo plantations to wider growing areas.

This study on bamboo species-site suitability matching for Ethiopia is intended to identify the bamboo species currently planted in the country and inform actors in the bamboo value chain about the growth performance of each specie and its suitability for planting in different agroecological zones. This report captures the origin of each bamboo species, its growth performance in its native range and in the various agro ecological zones in which it is currently grown, and its potential for ecological and socioeconomic utilization in different parts of the country. The report is intended to serve as a guide for farmers, foresters, and extension agents on matching each bamboo species to its most suitable agro ecological zone in the country. It is expected that this information will provide bamboo growers and value chain actors with much-needed confidence for decision-making on bamboo production and utilization on a commercial scale.

Ali Mchumo
Director General

Table of Contents

Executive summary	6
1. General introduction.....	10
2. Methodology.....	12
3. Ecological distribution and growth characteristics of highland bamboo (<i>Oldeania alpina</i>)	15
3.1 Introduction.....	15
3.2 Distribution and growth characteristics of highland bamboo in Ethiopia	15
3.3 Uses of highland bamboo	25
4. Ecological distribution and growth characteristics of <i>Oxytenanthera abyssinica</i> (A. Richard) in Ethiopia	26
4.1 Introduction.....	26
4.2 Ecological distribution and growth characteristics of lowland bamboo in Ethiopia	27
4.3 Utilization of lowland bamboo in Ethiopia.....	35
5. Growth characteristics of exotic bamboo species in Ethiopia	36
5.1 Introduction.....	36
5.2 Site ecological conditions and growth characteristics of bamboo species introduced into Ethiopia	37
6. Identification guide for bamboo species in Ethiopia.....	44
6.1 Introduction.....	44
6.2. Description of introduced bamboo species available in literature	44
6.3. Description of Indigenous Species.....	51
7. Bamboo species-site suitability matching	53
7.1. Criteria used to define bamboo species-site matching maps	53
8. Conclusion and recommendations.....	56
8.1. Recommendations.....	57
References	59

List of Tables

Table 1. Field data collection approach.....	13
Table 2. Highland bamboo-growing areas in Ethiopia	16
Table 3. Growth performance of propagules established using rhizome-based propagation techniques three years after planting at a research site in Dinkara, Awi Zone, Ethiopia	19
Table 4. Site characteristics of the study areas for highland bamboo	21
Table 5. Average number of culms per hectare per age classes in the studied districts	22
Table 6. Mean of dendrometric variables across locations per age class	24
Table 7. Geographic and agroecological information on 13 lowland bamboo-growing sites in three regional states of Ethiopia	30
Table 8: Growth characteristics of lowland bamboo in natural and planted sites	33
Table 9. Geographic and agroecological information and climatic conditions of the growing sites of exotic species.....	38
Table 10. Growth characteristics values (average) of the introduced bamboo species across experimental sites	43
Table 11. Environmental attributes required for highland and lowland bamboo plantation grouped under two suitability classes	53
Table 12. Suitable areas for indigenous bamboo species plantation in Ethiopia.....	54

List of Figures

Figure 1. Highland bamboo vegetative propagation trial in Banja District: (a) planted offset, and (b) culms sprouting from offsets.....	18
Figure 2. <i>Oxytenanthera abyssinica</i> (low land bamboo) in Ethiopia.....	31
Figure 3. Growth performance (DBH and height) of <i>Dendrocalamus asper</i> along an altitudinal gradient in Ethiopia and between two global locations (Ethiopia vs. origin)	39
Figure 4. Growth performance (DBH and height) of <i>Dendrocalamus hamiltonii</i> along an altitudinal gradient in Ethiopia and between two global locations (Ethiopia vs. origin)	40
Figure 5. Growth performance (DBH and height) of <i>Dendrocalamus membranaceus</i> along an altitudinal gradient in Ethiopia and between two global locations (Ethiopia vs. origin)	41
Figure 6. Growth performance (DBH and height) of <i>Dendrocalamus giganteus</i> along an altitudinal gradient in Ethiopia and between two global locations (Ethiopia vs. origin)	41
Figure 7. Clump of <i>Dendrocalamus asper</i> bamboo	45
Figure 8. Clump of <i>Dendrocalamus giganteus</i> bamboo.....	46
Figure 9. Stands of <i>Bambusa vulgaris</i> var. <i>vittata</i>	47
Figure 10. Growing <i>Bambusa balcooa</i> clump at Wondogenet.....	48
Figure 11. <i>D. hamiltonii</i> stand at Piccolo Abbai in Amhara Region	49
Figure 12. <i>G. amplexifolia</i> stand (Tepi, Ethiopia).....	50
Figure 13. <i>Oldeania alpina</i> stands (Hula District)	51
Figure 14. Lowland bamboo stand, culm with sheath and fruit structure	52
Figure 15. Experimental sites of introduced exotic bamboo species across the country.....	52
Figure 16. Map of suitable areas for highland bamboo plantation in Ethiopia	55
Figure 17. Map of suitable areas for lowland bamboo plantation in Ethiopia	55

Executive summary

Ethiopia's population has already been one of the largest in Africa, and it has caused an increased 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 must catch up 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. Ethiopia has 1.47 million hectares of natural bamboo forest, the largest in the African continent. Despite the versatile resource base and advanced bamboo utilization at a global scale, its great potential to enhance socio-economic and ecological development still needs to be realized in Ethiopia. Materializing the untapped potential of bamboo, Ethiopia has developed the National Bamboo Strategy and Action Plan (2019 - 2030) 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 significant 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 Ethiopia's agroecological zones (AEZs) need to be increased. This knowledge is vital in prioritizing and promoting bamboo farming for environmental, social, and economic transformation. This report thus presents findings of the bamboo site-species suitability matching study for Ethiopia. In particular, this report validates the ecological distribution and growth characteristics of indigenous highland and lowland bamboo species and introduced exotic species.

Both secondary and primary data were collected for this study. The secondary data were collected by reviewing published and unpublished literature on bamboo. Preliminary data was collected through semi-structured interviews with key informants from the National Forestry Research Institute, INBAR, Zonal Forest Officers, bamboo associations/organizations, and bamboo farmers. A field reconnaissance survey was carried out to assess bamboo-growing zones and districts. Zones in which the species grow widely were identified in consultation and discussions with regional experts; in sequence, growing areas at the district level were

identified in consultation with zonal experts, as was the identification of growing areas at the Kebele¹ level.

Finally, from selected zones, central bamboo-growing districts were considered for data collection. In each district studied, three sample plots were selected for data collection. The plot size for the data collection was 400 m² (20 m × 20 m). In each plot, all relevant parameters, including DBH, height, number of nodes, internode length, spacer length or rhizome neck, culm colour, and features of the nodal region (e.g., the shape of the culm sheath), were recorded. The tools used for this data collection included callipers, a diameter tape, and a measuring tape. Morphological characteristics of lowland, highland, and exotic bamboo species were documented. Composite soil samples dug from three pits 0 - 30 cm deep were taken from each plot to determine selected physical and chemical soil properties. Rainfall and temperature data were drawn from secondary sources, primarily district and zonal reports of the respective sites and from the published literature.

Highland bamboo is an economically important species that is naturally grown and adopted by smallholder farmers in Ethiopia for economic and social benefits. The report recommended that highland bamboo plantations to be established on sites with elevations of more than 2300 meters above sea level up to 3500 m.a.s.l, mean annual rainfall of more than 1200 mm, and temperatures ranging from 6 to 30 degrees Celsius. In this climatic conditions the growth performance of the highland bamboo observed is: the average DBH of highland bamboo ranges between 4.7 cm and 8.2 cm, and the average height ranges between 10.3 m and 15.0 m. The average internode length of highland bamboo at a height of 1.3 - 3 m ranges from 33.2 cm to 71 cm. Based on the scientific justification, the appropriate sites for planting highland bamboo in Ethiopia are: Chenchu Zuri, Masha, Gurage (Eja and Gumer) in the Southern Nations, Nationalities, and Peoples' Region. Furthermore, preferable climatic conditions are: altitude 2571 - 2899 (m.a.s.l.); annual rainfall 1061 - 1386 (mm); temperature 10.6 - 25.1 (°C); and soil slope 0 - 5 (%). The ideal climate conditions for Dire-Dawa and Seka Chokorsa in the Oromia region are altitude 2454 - 2463 (m.a.s.l.); annual rainfall 1340 - 1554 ((mm); temperature 7.8 - 23.6 to (°C); and soil slope 2 - 5 (%). Hula in the Sidama region requires altitude 2735 - 2744 (m.a.s.l.); annual rainfall 1313 - 1406 (mm); temperature 5 -18 (°C); and soil slope 2 - 5 (%). Sinan and Banja in the Amhara region necessitate altitude 2879 - 2946 (m.a.s.l.); annual rainfall 1240 - 1629 (mm); temperature 8 - 21 (°C); and soil slope 5 - 8 (%).

¹ Kebele is formal and the lowest administrative structure of local government in Ethiopia.

In addition, the report highlighted that there are approximately one million hectares of potential land in Ethiopia that could be used for the plantation of highland bamboo.

Lowland bamboo is more localized in its distribution across the Western and North Western parts of Ethiopia. It has aggressive growth and high productivity potential, provided silvicultural management practices (protection, spacing, and weeding) are implemented. The species was found to exhibit good growth performance at the studied sites, with an altitudinal range of 1100 m.a.s.l. to 1765 m.a.s.l. and a slope of 5 - 60%. The species grows well with an annual rainfall of > 500 mm and an annual temperature range of 17 °C to 35 °C. As such, revealed suitable areas to plant lowland bamboo in Ethiopia are Benishangul Gumuz; West Gojam, Amhara; Wondogenet, Sidama; and Dabo, West of Oromia. The growth performance of the lowland bamboo observed in the study is: 3.7- 4.4 cm average DBH and 9 -13 meters culm height.

Ethiopia has introduced and tested a total of 23 exotic bamboo species from Southeast Asia in order to study their adaptability to various agro-climatic zones. The site-specific matching study revealed seven exotic species that are highly suitable that perform well in terms of adaptability and growth performances in various agro-climatic zones. These species include *B. vulgaris*, *B. bamboos*, *B. balcooa*, *D. asper*, *D. hamiltonii*, *D. membranaceus*, and *D. giganteus*. The recorded growth performance of these species is: *D. asper* (DBH: 7.06 - 11.99 cm, and culm height: 20 - 21 m); *D. hamiltonii* (DBH: 4.7 - 8.4 cm, and culm height: 11 - 20 m); *D. giganteus* (DBH: 15.13 - 17.88 cm); *B. vulgaris* (DBH: 3.5 - 8.17 cm and culm height 13 - 15 m); *B. bamboos* (culm height 16 m and 7.77 cm DBH); and *B. balcooa* (20 m culm height and 7.98 cm DBH).

These exotic species are suitable for commercial cultivation and industrial utilization in different agro-climatic zones and locations. Based on the field trials, the study found that *D. hamiltonii* and *B. vulgaris* are performing well in Awi (Amhara); Jimma (Oromia); Wondogenet (Sidama); and Sheka and Gamo zones (SNNPRS) where the annual rainfall ranges from 980 – 1725 (mm); elevation ranges from 1188 – 1920 (m.a.s.l.); and temperature from 8.9 – 36 (°C). *D. asper* is performing well in Wondogenet (Sidama) and Awi (Amhara) where the annual rainfall ranges from 1372 – 1725 (mm); elevation ranges from 1700 – 1920 (m.a.s.l.); and temperature from 11.5 – 28.6 (°C). *B. bambos* and *B. balcooa* were found to perform well in Tepi, SNNPRS where elevation is 1200 (m.a.s.l.); average annual rainfall is 1678 (mm) and temperature ranges from 15 – 30 (°C).

Furthermore, the study also revealed that the growth performance of *D. membranaceus* and *D. giganteus* is not satisfactory in most of the experimental sites of the study.

The study is an informative guide to grow suitable bamboo species and sites in different agro-climatic zones in Ethiopia and promote commercially valuable bamboo species for environmental protection as well as industrial utilization. The report will help implement the Ethiopian Bamboo Strategy and Action Plan (2019 - 2029) and provide policy makers with the necessary data to make informed decisions concerning the expansion and improvement of the bamboo industry.

1. General introduction

Bamboo is a woody perennial plant that occurs naturally in tropical and subtropical belts and is commonly found in Africa, Asia, and Central and South America (Lobovikov *et al.*, 2007). Ethiopia is one of the few countries in Eastern Africa with considerable bamboo resources (Kelbessa *et al.*, 2000). Notwithstanding a versatile resources base and advanced bamboo utilization on a global scale, the considerable potential of the bamboo industry to enhance the socioeconomic and ecological development of Ethiopia remains unrealized (Zenebe *et al.*, 2014).

Bamboo is one of the most important non-timber forest products occurring naturally in the tropical and subtropical belts between Latitude 46° north and Latitude 47° south (Lobovikov *et al.*, 2007). Taxonomically, bamboo belongs to the family *Gramineae* (Poaceae) and there are more than 1,600 species of bamboo growing in natural stands and plantations all over the world (Canavan *et al.* 2017). Most bamboo species grow in Asia, with only 43 species that grow in Africa—of which 40 are found in Madagascar, while the remaining three species are found in mainland Africa. Notwithstanding the low diversity of bamboo species, Ethiopia, Kenya, and Uganda possess considerable bamboo resources (Lobovikov *et al.* 2007). For instance, based on a recent remote sensing based inventory conducted by the International Bamboo and Rattan Organization (INBAR) and Tsinghua University, Ethiopia has a total of 14,744.63 km² (i.e., 1.47 million ha) of bamboo-covered land (INBAR, 2018) and three million ha of land suitable for bamboo forest plantations and restoration (EFCCC and WRI, 2020).

Bamboo in general has a wide range of uses and value, including ecological benefits and benefits to the natural ecosystem (Mera and Xu, 2014). Recently, the use of bamboo has been growing rapidly (Piazza and Shyam, 2007) in biodiversity conservation, soil and water management (Bystriakova *et al.*, 2003; Zhou *et al.*, 2005), land rehabilitation, landslide control, and carbon sequestration (Zhou *et al.*, 2005). Furthermore, bamboo is an excellent substitute for wood in the production of pulp, paper, boards, charcoal (Piazza and Shyam, 2007), furniture, fences, and handicraft, and in the construction industry; plus, being valuable as edible shoots and animal fodder (Kelbessa *et al.*, 2000; Brias *et al.*, 2009). Currently, wood-based businesses such as Adal Industrial Plc. and SA Bamboo in Addis Ababa, Ethiopia, use highland bamboo (*Oldeania alpina*) in the production of flooring tiles, lumber furniture, incense sticks, stick-based products such as tooth picks, and energy products such as charcoal briquettes (INBAR, 2018). A value chain study by INBAR reveals that the current bamboo

resources in Ethiopia are not effectively managed, and the quality and quantity of the bamboo resources currently available at specific sites are insufficient to feed large-scale industries (INBAR, 2018). Therefore, improving the management of existing natural and plantation bamboo forests, and establishing new model bamboo plantations in potentially favorable areas of the country, for high-quality and sufficient bamboo culm production in sufficient quantities should get the attention and support of the government and nongovernmental actors.

Regarding the value-added utilization of bamboo in Ethiopia, there is growing demand for bamboo products among local processors, industrial product manufacturers, and household users. However, there are no guidelines with descriptions of the bamboo species in the country for ease of identification by bamboo growers and extension staff in the field. There is also a dearth of information among bamboo processors on the preferred uses of particular species. In addition, insufficient information on the growing conditions required for the various species is hindering expanding bamboo farming to wider growing areas. To bridge the gaps in the sector, the Dutch-Sino-East Africa Bamboo Development Programme (Phase-II) has been engaged by the Ethiopian Environment and Forest Research Institute (EEFRI) to study the growth performance of different bamboo species and develop identification and species-site matching guidelines for exotic and indigenous bamboo species, along with their potential utilization.

2. Methodology

Highland Bamboo: A field reconnaissance survey was carried out in Sidama, Oromia, Amhara, and the Southern Nations, Nationalities, and Peoples' Region (SNNPR) to assess bamboo-growing zones and districts. Zones in which the species grow widely were identified in consultation and discussions with regional experts; in sequence, growing areas at the district level were identified in consultation with zonal experts, as was identification of growing areas at the kebele level. Finally, from selected zones, major bamboo-growing districts were considered for data collection. In each district studied, three sample plots were selected for data collection. The plot size for the data collection was 400 m² (20 m × 20 m). In each plot, the number of culms was counted, and the internode distance, diameter at breast height (DBH), and the height of ten culms belonging to different age groups were measured.

Indigenous and Exotic Species: Field assessment was conducted in Benishangul-Gumuz Regional State (Pawe District, Metekel Zone), Amhara Regional State (Jawi and Gangua districts, Awi Zone), Oromia Regional State (Dabo District, Buno Bedele Zone), and Sidama Regional State (Wondo Genet District). In each district studied, three sample sites were selected based on the coverage and performance of lowland bamboo. A representative sample plot measuring 20 m × 20 m (400 m²) was established at each selected site. Growth parameters such as culm DBH and culm height were measured by categorizing bamboo culms into three age classes: <1 year, 1–3 years, and >3 years. Clump size (i.e., the perimeter of the clump at a height of 30–40 cm from the ground) was measured using a meter tape, and the number of culms per clump and the number of clumps per plot in the field were also counted. Geographic information (latitude, longitude, and altitude) was recorded using a Garmin eTrex GPS device, and slope was measured using a clinometer (Table 1).

Species Description: Morphological characteristics of lowland, highland, and exotic bamboo species were documented. In addition, pictures were taken to supplement the descriptions of the plants at the various stages of the bamboo life cycle. Information on the species from Flora of China, the Plant Resources of South-East Asia (PROSEA) database (2020), the Plant Resources of Tropical Africa (PROTA) database (1989), and Flora of Ethiopia and Eritrea (1995) was also considered.

Study Site Information: Composite soil samples dug from three pits 0–30 cm deep were taken from each plot to determine selected physicochemical soil properties. Rainfall and

temperature data were drawn from secondary sources, primarily district and zonal reports of the respective sites, and from the published literature.

Table 1. Field data collection approach

Data collection approach and method	Growth data collected	Geographic and climatic variables considered	Soil sample
Field reconnaissance survey. Consultation and discussions with regional, zonal, and district experts. A plot size of 400 m ² (20 m by 20 m) was used. Three sites selected per district/zone.	Number of culms per plot was counted for highland bamboo. Number of culms per clump and number of clumps per plot were counted for lowland bamboo. Number of culms by age class (<1 year, 1–3 years, and >3 years) within each plot. Height of culms per age group DBH of culms per age class Internode length at DBH	Latitude, longitude, and altitude. Slope. Rainfall Temperature	Composite soil samples (0–30 cm) were taken by mixing soil samples collected from three pits dug per plot.

Desk Review: Published and unpublished materials from various international and Ethiopian sources were reviewed for general information on the utilization, growth characteristics, site requirements, and prominent morphological features of lowland, highland, and exotic bamboo species.

Group Discussion and Key Informant Interviews

Information was collected from key informants and via focus group discussions. Ten to twelve people were selected for focus group discussions from among elders in the community who had at least 20 years of experience in bamboo cultivation. Three to five people with at least five years of experience in bamboo processing and trading participated in the group discussions and key informant interviews. For the focus group discussions and key informant interviews, a checklist was prepared based on the characteristics and woodworking properties of each specie. Furthermore, the qualitative data was collected during the focus group discussions and key informant interviews and recorded with the voice recorder to use it for data analysis

Data Collection on Culm Characteristics

All relevant parameters, including DBH, height, number of nodes, internode length, spacer length or rhizome neck, culm color, and features of the nodal region (e.g., shape of the culm sheath), were recorded. The tools used for this data collection included calipers, a diameter tape, and a measuring tape.

3. Ecological distribution and growth characteristics of highland bamboo (*Oldeania alpina*)

3.1 Introduction

Ethiopia possesses a significant amount of bamboo resources, comprising highland and lowland bamboo species. The geographical distribution of bamboo is governed predominantly by climate and soil conditions (Kowit *et al.*, 2001). Highland bamboo (*Oldeania alpina*) grows naturally in the south, southwest, central, and northwest highlands of Ethiopia at altitudes ranging from 2,200 to 4,000 m.a.s.l. (Kelbessa *et al.*, 2000). The highland bamboo species covers a large area between Bale Mountain, Bonga, and Metu, stretching from the south to the southwestern part of the country and Dangla in the north (Azene, 2007).

Because of its multipurpose nature, the species has considerable economic and social importance. In Ethiopia, nearly 750,000 people are engaged in bamboo cultivation, management, or utilization as a source of livelihood (EFCCC, 2017; Mekonnen *et al.*, 2014). The species grows rapidly and starts to yield usable culm within three to four years after planting via offset (1–2-year-old culms with rhizomes). The biomass growth of highland bamboo is more rapid than that of any other tree species (Teshome, 2015).

Till date, Ethiopia has not benefited from its bamboo resources due to a lack of technical knowledge on bamboo management and utilization (Mulatu, 2012; Wang, 2006). The available published and unpublished literature dealing with the species in Ethiopia also does not provide in-depth information on the determining factors that contribute to highland bamboo distribution across the country or on the production potential of the various species in different agro climates.

3.2 Distribution and growth characteristics of highland bamboo in Ethiopia

3.2.1. Distribution of highland bamboo in Ethiopia

In Ethiopia, the highland bamboo is distributed in mountain forest zones, often growing on volcanic soils, forming extensive pure stands, and occurring in *Afrocarpus falcatus* (*Podocarpus falcatus*) rainforests and with *Juniperus procera* in drier forests. Highland bamboo is found in different parts of Ethiopia as forest stands and plantations. Highland bamboo-growing areas are presented in Table 2, as summarized by Mulatu *et al.* (2016) and

a field survey. The most common rainfall range is 1200–4000 mm per year (Kelbessa *et al.*, 2000; Brias and Hunde, 2009).

Table 2. Highland bamboo-growing areas in Ethiopia

Region	Zone	District/District
Amhara	South Gondar	East and West Estie, Farta, Lay Gaiint
	Awi Zone	Banja, Fagita, Ankasha-Guagusa, Guagusa-Shikudad
	East Gojjam	Sinan, Bibugn, Machakel
	West Gojjam	Sekela, Dega Damot
	North Shoa	Tarmaber
	South Wollo	Debre-Sina
Oromiya	West Arsi	Koffale and Arsi-Negele
	Bale	Goba
	West Shoa	Dire Inchini and Shenen
	Jimma	Dedo, Seka-Chekorsa, Mana, Kersa, Agaro, Gera, Gera-Lola
Sidama Region		Hula, Arbegona, Bensa
The Southern Nations, Nationalities, and Peoples' Region	Gedeo	Bule, Yirga Chefe, Kochore
	Gamo	Chencha, Arba Minch Zuria, Bonke, Kamba, Boreda, Kucha, Mirab Abaya, Deramalo, Dita,
	Gofa	Geze-Gofa
	Guraghe	EZA, Gummer, Cheha, Geta, Enemore, Endegagn, Sodo, Muhirna Aklil, Gedabano Gutazer Welene,
	Hadya	Misha, Anlemo, Duna
	Kembata	Angecha, Doyo Gena
	South Omo	North Ari, South Ari
	Kefa	Gawata, Decha, Adiyo, Gesha, Dawro Zone (Tercha, Esera), Segen Hizboch (Amaro)
	Wolayta	Sodo Zuria
	Sheka	Masha, Anderacha, Debub Bech, Mizan Teferi- Kulish, Wushwush-Bonga, Bonga-Ameya

Source: *Mulatu et al. (2016) and Field Survey (2020)*

3.2.2. Growth characteristics of highland bamboo

Information on the growth patterns of highland bamboo and the period for culm emergence is critical for managing bamboo stands (Banik, 2008). Culm emergence primarily takes place at the beginning of the rainy season. Just after the appearance of culms on the ground, the culms elongate very slowly for one to two weeks and then gradually gain speed until they attain their optimum size, after which the rate of elongation quickly slows down. The culm is covered in a culm sheath, and almost all of its vertical growth (height) occurs before the emergence and development of branches.

Branching begins either after the culm has ceased elongation or in its subsequent growth season. Leaves start developing within two to four weeks of the development of branches. The development of leaves and branches arising at the culm nodes above the middle portion of the culm continue into the dry season. A one-year-old culm has fewer leaves than older culms. Significantly more leaves are found in two-year-old bamboo culm, and subsequently, the number of leaves decreases as culm age increases (Islam and Banik, 2005). For instance, a five-year-old culm has only a few leaves, which contributes a little to photosynthesis and the overall health of the clump (Banik, 2008).

The number and diameter of new culms that develop in a young stand increase with the age of stand until the stand reaches its maximum production potential, which is associated with the maximum culm size and stocking. Thus, the age of a bamboo stand is the determining factor for predicting the growth of *Oldeania alpina*.

Bamboo stands are established using three methods in various parts of Ethiopia:

- Seed-based planting materials;
- Offset or rhizome with culm-based planting materials;
- Natural regeneration (NR) or assisted natural regeneration (ANR) after flowering in pure bamboo forests and bamboo mixed forests.

3.2.2.1. Growth characteristics of highland bamboo seeds

Highland bamboo flowers and sets seeds once in a lifetime. The seeds of highland bamboo are viable for a limited time—seldom for more than 10 months (Brias and Hunde, 2009). Seeds are typically collected from a flowered bamboo seed set and are then planted and raised in nurseries with the appropriate care, just like other tree seedlings. Fresh and pure seeds of *O. alpina* have shown a best germination rate of 73% (Tinsae *et al.*, 2012). However, the germination rate drops by more than 50% in five months. Because of this poor viability, seeds need to be collected and immediately sown in a nursery.

Seedlings of the appropriate size (i.e., a 40–50 cm height) need to be planted in the field and then require serious follow-up involving soil moisturization, cultivation and weeding, and protection from herbivores for the first two years for better survival and growth. In addition, naturally regenerated or rehabilitated seedlings (i.e., wild seedlings) sprout from fallen seeds of flowered highland bamboo stands if protected from livestock browsing and assisted via weeding.

3.2.2.2. Growth of highland bamboo offsets

In the studied areas, local communities plant highland bamboo using the offset method. A study conducted in Banja District, Amhara Region reveals that propagation of highland bamboo using a four to six node culm with rhizomes produced outstanding culms in terms of shoot production and quality (Kebede *et al.*, 2017) (Table 3). Culms as propagules should be separated from clumps carefully, and then shortened to the node above the first branches (Brias and Hunde, 2009), typically the fourth and sixth node (Kebede *et al.*, 2017). This offset method is difficult to implement on a large-scale bamboo plantation because it is a lengthy process, and the propagules are heavy for transporting (Brias and Hunde, 2009). The propagules should be collected at the onset of the rainy season, just before the emergence of new shoots, and the offsets or rhizomes should be kept in soil-filled gunny bags till planted.

The planting site should be cleared and plowed to prevent woody growth, and fenced to prevent grazing animals during the establishment period. Protecting a bamboo stand from animals significantly improves bamboo forest productivity. In addition, soil conditions, including soil moisture content and soil porosity, have a significant effect on bamboo productivity, i.e., culm thickness (Nigatu *et al.*, 2020).

It is also recommended to dig pits before the planting season and to keep watering the soil for some time. For rhizome offset planting, the pit size should be at least 50 × 50 × 50 cm. Large pits provide sufficient working space for the easy establishment and growth of bamboo rhizomes. Thin culms have been observed sprouting in the year of planting, but the thickness of the culms that sprout in the next year has a superior culm size, which improves over the seasons (Figure 1b).



Fig 1a



Fig 1b

Figure 1. Highland bamboo vegetative propagation trial in Banja District: (a) planted offset, and (b) culms sprouting from offsets

Table 3. Growth performance of propagules established using rhizome-based propagation techniques three years after planting at a research site in Dinkara, Awi Zone, Ethiopia

	Rhizome with whole culm (offset)	Rhizome with two nodes	Rhizome with four nodes	Rhizome with six nodes	Rhizome without culm
Mean number of sprouted culms	3.24 ± 1.48	5.81 ± 1.7	5.81 ± 1.5	5.71 ± 1.58	4.62 ± 1.39
Mean height (cm)	97.76 ± 29.07	99.81 ± 20.39	137.02 ± 22.94	119.48 ± 26.11	67.1 ± 17.97

Source: (Kebede *et al.*, 2017)

3.2.2.3. Growth characteristics of highland bamboo (findings from experimental research by EEFRI) under different harvesting intensity regimen

Sustainable bamboo stand/forest management practices can facilitate making the right decisions regarding the timing and quantity of bamboo culms to be harvested each year. Appropriate harvesting techniques can enable the rehabilitation of previously unmanaged bamboo stands, as well as sustainably increase growth, i.e., yield, height, culm diameter, and the number of shoots (Mulatu *et al.*, 2016). Culm production depends primarily on the harvesting regimen (Kleinhenz and Midmore, 2001). A study conducted to understand the effect of selective harvesting found that selective harvesting of 75% of the mature culms improves highland bamboo forest productivity (Getahun *et al.*, 2019) by increasing recruitment, height, internode length, and the thickness of new culms over the years. Kigomo (2007) also reports that the removal of mature culms maintains the vigor of the plants and facilitates continuous generation of new shoots. Furthermore, Sutiyono (1987) observed that the productivity of bamboo stands deteriorated due to herbivory, poor harvesting approaches, and over-harvesting of young bamboo culms. When then harvesting of mature culms is not performed, culm production gradually decreases over the seasons. In addition, Mulatu *et al.*, (2016) also found that soil loosening improves highland bamboo productivity. However, the clear-felling of bamboo stands is unadvisable because recovery of a clear-felled stand takes a long time (PROTA, 1989).

Management practices such as soil loosening, removing dead rhizomes and stumps, and selective thinning of mature culms improve bamboo productivity via increasing culm recruitment and the reduction of shoot mortality (Mulatu and Fetene, 2013).

Furthermore, bamboo harvesting should be done during the dry (dormant) season. Harvesting during the dormant season ensures vigorous regrowth of sprouting shoots (Hytönen, 1994; Ceulemans *et al.*, 1996). Cutting during the active growing season increases shoot mortality and decreases growth compared with cutting during the dormant season. This is because, during the growing season, stored reserves are transferred from the roots to aboveground parts of the plant to initiate growth (Shultz, 2007). Harvesting during the active growing season causes the plant to respond poorly or activate sprouting; however, the underground parts may not have sufficient stored reserves to allocate to sprouting (Hytönen, 1994; Ceulemans *et al.*, 1996), as the stored reserves have already been used to initiate growth. In addition, because the bamboo culm is particularly susceptible to destructive organisms, cutting during the active growing season exposes bamboo culms to fungus and insect infestation (Mulatu *et al.*, 2016). However, the harvesting frequency is determined by the grower based on to their needs (Seyoum *et al.*, 2018), which may cause the productivity of *Oldeania alpina* forests to deteriorate.

3.2.2.4. Stand structure of highland bamboo in the studied areas

To study the actual situation of the stand structure under existing conditions, the major bamboo-growing areas were visited, and data were collected from various regions. The site characteristics of the studied areas are presented in Table 4. The altitudinal range of the study sites lies between 2,387 to 2,979 m.a.s.l. The mean annual rainfall is between 1,123 mm and 2,144 mm.

Table 4. Site characteristics of the study areas for highland bamboo

	District	Plot	Longitude	Latitude	Altitude (m.a.s.l.)	Slope (% or degree)	Rainfall min-max (mm)	Temperature min-max (°C)
1	Chencha	1	037° 34' 02.4"	06° 12' 44.3"	2571	0-2	1061-1169.70	10.6-24.2
		2	037° 33' 56.8"	06° 13' 01.7"	2564	0-2		
		3	037° 34' 04.7"	06° 12' 58.9"	2557	5-8		
2	Gurage (Eza and Gumer)	1	038° 07' 00.7"	08° 06' 26.5"	2925	5-8	1042.70-1386.10	8.4-25.1
		2	038° 05' 54.0"	07° 59' 25.4"	2899	2-5		
		3	038° 04' 20.6"	08° 00' 31.2"	2899	2-5		
3	Dire Inchini	1	037° 38' 17.8"	08° 50' 40.4"	2454	2-5	1339.70-1554.60	7.8-23.6
		2	037° 38' 16.3"	08° 50' 40.8"	2467	2-5		
		3	037° 38' 19.2"	08° 50' 41.4"	2463	2-5		
4	Hula	1	038° 33' 18.4"	06° 28' 50.6"	2744	2-5	1313.50-1406.40	5.3-18.6
		2	038° 33' 14.6"	06° 28' 54.8"	2712	5-8		
		3	038° 33' 19.1"	06° 28' 57.6"	2735	2-5		
5	Sinan	1	036° 4' 9.06"	11° 67' 8.56"	2879	45-60	1239.40-1626.90	8.2-21.7
		2	036° 5' 4.22"	11° 67' 8.70"	2979	30-45		
		3	036° 5' 0.45"	11° 67' 9.30"	2946	5-8		
		4	036° 5' 0.19"	11° 67' 9.95"	2946	5-8		
6	Masha	1	035° 30' 09.9"	07° 37' 09.2"	2423	0-2	2072.50-2190.90	8.4-23.1
		2	036° 47' 31.2"	07° 40' 22.2"	2505	2-5		
		3	035° 30' 25.6"	07° 36' 27.1"	2478	0-2		
7	Banja	1	036° 57' 50.6"	10° 54' 79.0"	2500	2-5	2061.20-2237.20	8.2-23.8
		2	036° 57' 27.8"	10° 54' 67.0"	2481	5-8		
		3	036° 56' 7.77"	10° 56' 34.4"	2539	5-8		
8	Seka Chokorsa	1	036° 35' 66.9"	07° 42' 92.7"	2387	0-2	1568.10-1703.60	7.6-24.1
		2	036° 38' 50.5"	07° 42' 99.3"	2571	2-5		
		3	036° 39' 15.8"	07° 42' 84.8"	2552	5-8		

Source: Field Survey, 2020;ENACT Climate Database

The structure of a bamboo stand is indicative of the growth and productivity of bamboo plantations and forests. Stand structure comprises the vertical and horizontal organization components of bamboo clumps (culms and rhizomes) as a function of age and number, which reflects its properties and functions. High highland bamboo forest productivity can be achieved with the proper density, age, and size of culms and rhizomes.

Table 5. Average number of culms per hectare per age classes in the studied districts

Age class	Chencha	Gurage (Eja and Gumer)	Dire Enchini	Hula	Sinan	Masha	Banja	Seka Chokorsa
<1 year	1,432.5	1,692	1,550	1,450	1706	1,733.3	3,025	1,991.66
1–3 years	4,932.5	3,608	2,800	5,457.5	4,256	3,225	6,508	4,883.33
>3 years	4,200	2,508	900	900	5,493	1,466.6	2,033	2,116.66
Total	10,565	7,808	5,250	7,808	11,456	6425	11,566	8,992

Source: Field inventory, 2020

It was observed that productivity varied with the silvicultural practices applied. For instance, in bamboo forests owned by local communities and Orthodox churches, proper silvicultural practices were not implemented, including even harvesting mature culms. A distinct difference was observed between the stands in private bamboo forests and those in church/community owned bamboo forests across the sites. Darabant *et al.* (2016) also mentioned that the annual harvesting of mature culms over several years jeopardizes clump productivity.

The data from the studied sites show variability in the total culm number per hectare across sites. The highest culm number was recorded in Banja District (11,566 culms/ha) and the lowest was in Dire Inchini (5,250 culms/ha). Dire Inchini having the lowest culm number is attributed primarily to the market-oriented harvesting of select high-quality bamboo culms based on buyer interest. It also indicates that Dire Inchini bamboo producers have greater market access than bamboo producers in Banja District; hence, more culms per hectare are harvested and sent to the nearby Addis Ababa market. Common to many growing areas was that dead rhizomes and stumps are not extracted in most *O. alpina* growing areas. This again favors underground congestion and impedes running of young rhizomes and culm emergence.

In general, it was observed that there are too many poor and deformed mature bamboo culms in *O. alpina* stands in the study areas. This could affect the quality and quantity of new emerging bamboo culms by creating congestion and disrupting the allocation of stored energy reserves to the emergence of new culms. Similarly, Sutiyono (1987) indicated in his study findings that the productivity of bamboo stands deteriorates due to herbivory, over-harvesting of young bamboo culms, and poor harvesting approaches.

Generally, to ensure a sustainable supply of bamboo culms and create a healthy stand, selective harvesting of mature bamboo culms (older than three years) is recommended. This removal of mature culms also maintains the vigor of the younger culms and allows for the continuous generation of new shoots (Brias and Hunde, 2009) by minimizing competition for space among culms (Banik, 2008).

Table 6. Mean of dendrometric variables across locations per age class

Culm age	District	DBH (cm)			Height (m)			Internode length (cm)		
		<1	1–3	>3	<1	1–3	>3	<1	1–3	>3
1	Chencha Zuria	5.6 ± 1.2	6.1 ± 1.3	5.9 ± 1.6	10.7 ± 1.4	11.5 ± 1.7	11.4 ± 1.8	44.0 ± 5.0	44.0 ± 5.7	43.8 ± 4.1
2	Gurage (Eja and Gumer)	6.5 ± 1.6	6.3 ± 1.2	5.9 ± 1.6	12.0 ± 3.1	12.1 ± 2.6	10.7 ± 2.6	44.9 ± 8.6	46.7 ± 8.3	43.5 ± 8.4
3	Dire Enchini	6.0 ± 0.9	6.2 ± 1.2	5.1 ± 1.1	13.4 ± 1.2	13.6 ± 1.9	11.0 ± 2.2	40.2 ± 3.8	41.1 ± 3.8	40.0 ± 4.8
4	Hula	4.7 ± 1.2	5.1 ± 0.7	5.4 ± 1.2	8.1 ± 2.5	10.3 ± 1.8	10.3 ± 3.1	33.2 ± 7.2	36.7 ± 2.8	34.0 ± 4.8
5	Sinan	8.2 ± 1.5	7.9 ± 1.4	7.8 ± 1.5	14.6	15	15	66	67.5	71
6	Masha	6.5 ± 0.8	6.0 ± 0.9	5.4 ± 0.8	10.9 ± 2.1	11.3 ± 1.8	11.0 ± 2.0	47.8 ± 3.0	46.5 ± 3.0	45.2 ± 3.7
7	Banja	5.4 ± 1.3	5.1 ± 1.2	4.6 ± 0.9	7.2 ± 0.8			51.7 ± 6.4		
8	Seka Chokorsa	7.3 ± 1.2	7.1 ± 0.6	7.0 ± 0.6	12.5 ± 1.5	11.5 ± 1.6	12.6 ± 2.0	45.9 ± 3.6	43.6 ± 4.0	44.8 ± 3.8

Note:

- <1 refers bamboo culms less than one year,
- 1–3 culms one to three years old,
- >3 culms older than three years.

The average DBH of highland bamboo for Hula District and Sinan District were 4.7 cm and 8.2 cm, respectively. The average height of a highland bamboo culm varied between 8.1 m and 15.0 m (Table 6). The internodal length of an elongating culm increases gradually from the base toward the middle portion of the culm and then decreases upwards (Banik, 2008). The average internode length of highland bamboo at breast height ranged from 33.2 cm in Hula to 71 cm in Sinan. These results indicate higher values of growth parameters for Sinan District possibly due to Sinan have a higher site quality than the other sites (Table 6).

Both browsing and soil compaction by livestock affect the growth of rhizomes and roots (Getahun *et al.*, 2019), which forces the bamboo plant to allocate more resource to its aboveground biomass to withstand repeated browsing. This directly influences the number and mortality of new shoots sprouting. Similar studies have reported that protecting bamboo from herbivory increases the culm yield of previously unmanaged communal bamboo stands (Mulatu *et al.*, 2016). Furthermore, weeding is an essential practice as bamboo stand management at the early stages has been shown to improve bamboo stand productivity when practiced by local communities (Seyoum *et al.*, 2018). Therefore, herbivory protection is crucial.

3.3 Uses of highland bamboo

3.3.1. Local use in Ethiopia

Highland bamboo is used in fencing, house construction, furniture making (tables, stools, chairs, shelves), making wooden swords and knives, and building shade structures in bamboo nurseries, as well as for food as bamboo shoots and as fuel (charcoal and firewood).

3.3.2. Industrial use in Ethiopia

Highland bamboo is used to prepare traditional and modern furniture, toothpicks, sandal sticks, fuel (pellet and briquette), bamboo flooring, beams, veneer, decking, and house construction.

4. Ecological distribution and growth characteristics of *Oxytenanthera abyssinica* (A. Richard) in Ethiopia

4.1 Introduction

Oxytenanthera abyssinica, commonly known as *lowland bamboo* constitutes substantial majority of bamboo forests in Ethiopia. Lowland bamboo cover in Ethiopia accounts for 85% of the total national bamboo cover (Kassahun, 2000). However, estimates of the area coverage of lowland bamboo forests in the country change from time to time primarily due to the methodologies used to estimate the resource. Ensermu *et al.* (2000) and Luso Consult (1997) estimated lowland bamboo forest cover as 959,662 ha and 800,000 ha, respectively, using arial photographs and ground surveys. An inventory report performed by the Ministry of Environment, Forest and Climate Change (MEFCC) in 2017 estimated the total lowland bamboo cover of the country to be more than 462,650 ha (this estimate is for Benishangul-Gumuz alone). However, a very recent remote sensing based estimate by INBAR (2018) reports the lowland bamboo cover of the country to be more than 944,756 ha (this estimate is for Benishangul-Gumuz alone). The disparity in the data generated by different organizations can be attributed to the methodology employed. Nevertheless, studies by Semeneh *et al.* (2016) and INBAR (2010) indicate that the bamboo forests in major lowland bamboo-growing areas have been shrinking rapidly, which aroused fear that a large portion of the resource might be lost shortly. Lowland bamboo natural forests are considered open access resources and planned and unplanned drivers of deforestation, and the resource is degrading in both quality and coverage without the country seizing the golden opportunities presented by the resource for improving the livelihoods of its people and communities and enhancing its economy. Unclear forest ownership and the absence of a land use plan in the country are contributing significantly to the decline of the lowland bamboo resource. Furthermore, the coverage and productivity of lowland bamboo stands have been declining, and this is linked to a mass flowering event spanning the last ten years and a lack of management of the resource (e.g., protection from livestock and human interference and frequent forest fire).

Lowland bamboo is an economically and ecologically critical plant species native to Ethiopia and endemic to tropical Africa (Kristina and Juan, 2013). It is a tufted, sympodial bamboo with semisolid and solid culms with a maximum diameter of 10 cm (range: 5–10 cm) and a maximum height of 13 m (range: 3–13 m). Young shoots of the species can be distinguished by their bluish-green color and creamy yellow blades (Victor and Tesfaye, 2009).

Furthermore, lowland bamboo has versatile woodworking properties, such as a superior modulus of rupture (MOR) and modulus of elasticity (MOE), which make the species a superior substitute to other local and industrial forest products (Seyoum, 2007) derived from extended rotation forests in the country. Ecologically, the species grows in lowland areas (500–1800 m.a.s.l.) with very poor soils, even tolerating rocky soils, high temperatures averaging 20–35 °C, and low rainfall of approximately 600 mm (Yigardu *et al.*, 2016); hence the species has tremendous ecological potential. Biomass production of this species is extraordinary compared to all other woody plants in Ethiopia, making it the right species for climate change mitigation and adaptation.

4.2 Ecological distribution and growth characteristics of lowland bamboo in Ethiopia

4.2.1. Ecological distribution of lowland bamboo forests in Ethiopia

Lowland bamboo grows at an altitude of 500–1800 m.a.s.l., a mean annual temperature of between 20 °C and 35 °C, and a mean annual rainfall of 1,150 mm; but can also tolerate an erratic mean annual rainfall or one as low as approximately 600 mm (PROTA, 2016). In Ethiopia, lowland bamboos are confined to the western part of the country, which has moist and wet *Kolla* or lowland agro climatic zones. The larger proportion of Ethiopia's lowland bamboo forests are found in the Combretum-Terminalia deciduous woodlands of Western Ethiopia, together with other associated grasslands. The species is found in savanna woodlands, often forming extensive stands (Phillips, 1995), and it grows in five regions of Ethiopia: Benishangul-Gumuz, Oromia, Amhara, Tigray, and Gambella (Yigardu *et al.*, 2019). On the African continent, lowland bamboo is found in countries neighboring Ethiopia, such as Sudan and Kenya, and in Tanzania.

O. abyssinica grows on extremely poor soils and various types of parent rock, but much of its distributional range is on old crystalline basement complex, and soil fertility is not a major influence. *O. abyssinica* is associated with impoverished acrisols and ferralsols, moderately fertile luvisols, and younger relatively nutrient-rich cambisols and nitisols. The species is essentially absent from arenosols with poor moisture retention and gleysols with poor drainage (PROTA, 1998). Key site factors are good drainage, combined with access to reliable water supply. Characteristic habitats are ravine areas, drainage lines, termite mounds, and rocky slopes. Typical rocky slope microsites are well-illuminated gullies with deep soil accumulated between boulders. Saline conditions are unfavorable.

O. abyssinica constitutes a considerable proportion of the Combretum-Terminalia deciduous woodlands of the Benishangul-Gumuz Region followed by the Amhara Region, part of the Western Oromia Region, and the Gambela Region. Domestication of the species has also been underway in the aforementioned regions, Tigray and the SNNPR.

According to Yigardu *et al.* (2016), many districts in zones of the different regions of Ethiopia are recognized for their lowland bamboo potential:

(1) Benishangul-Gumuz Region: Assosa Zone (Bambassi, Assosa, and Homosha districts), Metekel Zone (Mankush, Mandura, Guba, Pawe, and Dibate districts), Kemash Zone (Kemash District), Mao-Komo Special District; (2) Oromia Region: Gimbi, Guten, Kelkon, and Leka; (3) Amhara Region: Awi zone (Jawi, Guangua, Ankesha, and Zigem districts), East Gojjam Zone (Debre Elias and Baso Liben districts), West Gojjam Zone (Bure, Wombera, and Dembecha districts), North Gondar Zone (Metema, Quara, Alefa, Tach Armach'ho, Tsegede, and Adiarkay districts); (4) Tigray Region: Mierabawi Tigray Zone (Tselemti, Welkait, Tahtay Adiabo, Asgede-Simbala, Tsegede, and Kafta Humera); (5) Gambela Region: There is lowland bamboo potential in many well drained areas.

4.2.2. Growth characteristics of lowland bamboo

The growth characteristics of lowland bamboo have been documented by Yigardu *et al.* (2016). Initial growth of lowland bamboo stands developed using the seedling and offset methods may vary slightly. Rhizomes of newly planted seedlings in the field develop shoots, which reach more than 1 m in height, with many thin culms forming clumps in the first year. Afterwards, during the next rainy season, both culm size and clump size increase considerably. Lowland bamboo is a vigorously growing species that produces a huge biomass in a short time.

A maximum culm height of five meters and more than 12 culms per clump at the age of two years was recorded in the Sherkole area of Homosha District. In another investigation at an EEFRRI experimental site in Jimma, planted seedlings of lowland bamboo produced 15 culms per clump, with an average height of 4 m and an average diameter of 3.5 cm, at the age of two years. Both culm and clump size increased dramatically in the third rainy season. Remarkably at three years of age, a clump had produced an average of more than 36 culms, with a maximum height of 8 m and an average diameter of 4.5 cm. Bamboo stands established using offsets are ready for harvesting in shorter time than those with a seedling origin. Thus,

under good management, stands established using offset methods are expected to begin production in the fourth year.

4.2.3. Ecological conditions and growth characteristics of natural and planted lowland bamboo forests (result of this study)

4.2.3.1. Ecological conditions of natural and plantation lowland bamboo forests

Field assessments were conducted in Benshangul Gumuz Regional State (Pawe District of Metekel Zone), Amhara Regional State (Jawi and Gangua districts of Awi zone), Oromia Regional State (Dabo District of Bunu Bedele Zone), and Sidama Regional State (Wondo Genet).

The altitude of the naturally growing sites ranged from 1,110 to 1,765 m.a.s.l. (Table 1). The lowest elevation (1,100 m.a.s.l.) was recorded for Mender-7 and Mender-10 kebeles of Pawe District in Metekel Zone. Two sites with the highest elevation were Abi Teklu Private Forest Plantation (1,700 m.a.s.l.) at Guangua District of Awi Zone and the site at the Wondo Genet Agricultural Research Center (1,765 m.a.s.l.). The private planted bamboo forest site at Abi Teklu was established using seedlings four years ago, and the site receives high rainfall (1,725 mm annually) and has a low temperature range (13.2–28.6 °C).

The slope of the study sites ranged from 5% (Pawe Mender-7) to 60% (Embasir Watershed in Simida Frint Kebele of Jawi District, Agew Awi zone). The three areas receiving highest annual rainfall were Dabo (1,854 mm), the Abdi Teklu Plantation site (1,725 mm), and Mender-7 (1,580 mm). The minimum rainfall (900 mm) is received at Sherkole, followed by the Addis Alem Gebriel, Guder-Kava, and Embasir watersheds (1,200 mm). The minimum temperature of the study sites varied from 11 °C at the Dabo site to 21 °C at Bambassi. The maximum temperature, on the other hand, ranged from 28.4 °C at the Abi Teklu private bamboo plantation to 31.4 °C at Jawi with Embasir plantation

Table 7. Geographic and agro ecological information on 13 lowland bamboo-growing sites in three regional states of Ethiopia

S. No.	Region	Zone	District	Plot	Latitude	Longitude	Altitude (m.a.s.l.)	Av. An. rainfall (mm)	Av. Min. Temp. (°C)	Av. Max. Temp. (°C)	Slope (%)
1	Benishangul Gumuz (BG)	Metekel	Pawe	Mender-7 (On-station, PARC)	11° 18.925' N	036° 25.09'E	1,110	1,596.3	14.2	31.9	5
2	Benishangul Gumuz (BG)	Metekel	Pawe	Mender-10	11° 19.364' N	036° 27.939'E	1,100				10–15
3	Benishangul Gumuz (BG)	Metekel	Pawe	Mender-12 (Debrework Mich.)	11° 19.714' N	036° 30.184'E	1,143				5–10
4	Benishangul Gumuz (BG)	Assosa	Bambasi	Ambesachaka	9° 54.453' N	034° 39.478'E	1,491	1,391.38	10.0	29.3	5–10
5	Benishangul Gumuz (BG)	Assosa	Homosha	Sherkole camp	–	–	–	1,127.22	10.9	29.4	5–10
6	Amhara	Awi	Jawi	Embahir	11° 25.258' N	036° 35.192'E	1,276	1,633.79	14.2	31.4	45–60
7	Amhara	Awi	Jawi	Addis Alem Gebriel	11° 24.413' N	036° 36.212'E	1,227				20–25
8	Amhara	Awi	Jawi	Guder-Kava	11° 37.274' N	036° 37.837'E	1,237				20–25
9	Amhara	Awi	Guangua	Abi Teklu Private Forest Land	10° 56.683' N	036° 30.544'E	1,700	1,432.69	11.0	28.4	45
10	SNNP	Sidama	Wondo Genet	Wondo Genet ARC	07° 05.506' N	038° 37.172'E	1,765	1,049.59	10.7	25.3	5
11	Oromiya	Buno Bedele	Dabo	Dabo (farmer)	07° 11.795' N	035° 25.296'E	1,370	1,716.92	10.4	26.8	5
12	Oromiya	Buno Bedele	Dabo	Dabo (church)	08° 39.836' N	036° 23.628'E	1,423				5
13	Oromiya	Buno Bedele	Dabo	Dabo (community)	08° 39.761' N	036° 23.754'E	1,434				5

Source: Field data and meteorological information from respective offices, 2020

4.2.3.2. Growth performance of lowland bamboo in the natural and planted forests

The average DBH of lowland bamboo in the 13 study sites ranged from 3.4 cm at the Jawi, Guder-Kava site to 5.3 cm at the Mender-7 site and 5.6 cm at Wondo Genet (Table 2). The Mender-7 site, which is located within the compound of the Pawe Agricultural Research Center in Metekel Zone, has culms with higher than average height (11 m) and a moderate number of culms (30) per clump. This plantation was established 13 years ago by the then Forestry Directorate of the Ethiopian Institute of Agricultural Research (EIAR).



Figure 2. *Oxytenanthera abyssinica* (low land bamboo) in Ethiopia

The highest number of culms (59, 57, and 56) per clump was recorded at Guder-Kava, Mender-12 (Debrework Michael Church), and the Abi Teklu Private Forest, respectively, while the lowest count (14) was at the Mender-10 site. Notwithstanding the high density of culms per clump, the Guder-Kava site had some of the lowest DBH and culm height, which may be related to challenges managing the clumps, and in part, n-site conditions. Apart from the high number of culms per clump, the Debrework Michael Church and Abdi Teklu Private Forest sites had a remarkably attractive number of clumps per plot, utilizing the area effectively. The relatively good performance of lowland bamboo at Wondo Genet and the Abdi Teklu private planted forest site indicates that lowland bamboo can perform well at mid-elevations.

The bamboo forest in Mender-10 (Pawe District) is a new forest regenerated after a mass flowering event in the area and is owned by a community group. The stand is exposed to interference from individuals from non-user groups in the surrounding areas. To quantify the level of disturbance, we randomly enumerated three clumps from three sample plots and observed that 15% of the culms were affected by clear-cutting and

50% of the culms were disturbed by cutting at higher stem positions; only 11% of the standing culms were economically valuable. However, Mender-10 had a relatively good average culm DBH size of 4.7 cm although its number of culms per clump was one of the lowest at 14.

The average DBH of culms for the 13 study sites was 4.4 cm, 3.7 cm, and 3.6 cm for culms aged <1 years, 1–3 years, and >3 years, respectively. Bamboo produces new shoots that are particularly thin in the first few shooting seasons after it is newly established via seedlings or via vegetative means. Afterwards, however, as the rhizome grows bigger, the emergent shoots grow bigger and the plant eventually reaches its maximum size. A decrease in DBH as the bamboo plant ages was observed in this study, which may be associated with the young age of the stands studied on the one hand and with problems of stand management on the other. However, this trend is fully dependent on sustainable harvesting and management practice.

Table 8. Growth characteristics of lowland bamboo in natural and planted sites

S. No.	District	Plot/ Kebele	Average DBH (cm)			Height (m)			No. of culms/ clump	No. of clumps /plot	Incidence of fire	Ownership (source)
			<1 year	1–3 years	>3 years	Mean	min	max				
1	Pawe	On-station, PARC (Mender -7)	5.3	3.74	3.91	11	9	13	30	13	None	Research organization (planted)
2	Pawe	Mender-10	4.69	3.42	3.95	11	9	13	14	19	None	Farmer
3	Pawe	Mender-12 (Debrework Michael Church)	4.78	3.66	3.5	11	9	13	57	77	None	Church (regenerated)
4	Jawi	Embasir (Simida Frint Kebele)	3.92	3.4	3.44	8	10.5	13	29	19	Once during farmland preparation	Community (regenerated)
5	Jawi	Addis Alem Gebriel	3.90	2.66	3.32	8	10.5	13	26	36	Once during farmland preparation	Farmer (regenerated)
6	Jawi	Guder-Kava	3.39	3.36	3.3	8	10.5	13	59	22	Once during farmland preparation	Farmer (regenerated)
7	Guangua	Abi Teklu private forest land	4.76	4.9	3.48	12	12	12	56	8	None	Farmer (plantation)
8	Wondo Genet	Wondo Genet	5.57	5.48	4.57	11.33	10.5	12	25	-	None	Research organization (planted)
9	Buno Bedele	Dabo	4.24	3.945	3.62	6.125	6	6.5	-	35	Once	Farmer (mature-natural forest)

10	Buno Bedele	Dabo	4.01	3.25	3.26	5.5	5	6	-	8	Once	Church (mature-natural forest)
11	Buno Bedele	Dabo (Community)	3.89	3.3	3.54	6	5.5	6.5	-	6	Once	Church (mature-natural forest)

4.3 Utilization of lowland bamboo in Ethiopia

In Ethiopia, lowland bamboo is extensively used for rudimentary products, local consumption, and local trade in domestic markets. The thin silvery stem sheath is extensively used in roofing and in the construction of traditional beehives, while the hollow bamboo is used to make traditional music instruments. The stem (culms) is cut into small pieces to make coffee cups and water jars. The primary bamboo products are traded at the local level for different purposes, including fencing, house construction, construction of cattle barns and grain stores, furniture making (stools, chairs, mats, etc.), basket making, tools, and firewood. Lowland bamboo shoots are used for food during the sprout season and a limited proportion of lowland bamboo culms are exported to a neighboring country, Sudan.

5. Growth characteristics of exotic bamboo species in Ethiopia

5.1 Introduction

In view of diversifying the genetic base of bamboo species as a resource, and with the objective of evaluating bamboo species that can grow at mid-altitudes, different bamboo species from Southeast Asia have been introduced into Ethiopia since 2007.

The first entry of ten exotic bamboo species, including *Dendrocalamus asper*, *Dendrocalamus hamiltonii*, *Dendrocalamus giganteus*, *Dendrocalamus membranaceus*, *Bambusa vulgaris* sub. var. *green*, *Bambusa vulgaris* sub. var. *vittata* and *Bambusa balcooa*, were introduced by the Ministry of Agriculture under the East Africa Bamboo Development Project. Subsequently, 16 species were introduced by Morel Agro industries Ltd. in collaboration with the Forest Directorate of EIAR. These species are undergoing multiplication at Bishoftu and Gurd Shola nurseries of the Central Ethiopia Environment and Forest Research Center, Addis Ababa. The species include *Bambusa balcooa*, *Bambusa bambos* Voss, *Bambusa multiplex* 'Alphonse Karr', *Bambusa multiplex* Silver stripe, *Bambusa oldhamii*, *Bambusa tulda*, *Dendrocalamus brandisii*, *Dendrocalamus giganteus*, *Dendrocalamus latiflorus*, *Gigantochloa apus*, *Gigantochloa atter* (Hassk.) Kurz ex Munro, *Gigantochloa kuring* 'Sumatra', *Guadua amplexifolia*, *Guadua angustifolia* Kunth, *Phyllostachys aurea* Carrière ex Rivière and C. Rivière, *Phyllostachys pubescens*, *Phyllostachys vivax* 'Aureocaulis' and *Schizostachyum jaculans*.

The species were trilled from seven genera, which include *Bambusa* (five species, two of which have sub varieties), *Dendrocalamus* (six species), *Gigantochloa* (three species), *Guadua* (two species), *Phyllostachys* (five species), *Schizostachyum* (one species), and *Thyrsostachys* (one species) (Yigardu *et al.*, 2016). Seven species: *Dendrocalamus asper*, *Dendrocalamus hamiltonii*, *Dendrocalamus giganteus*, *Dendrocalamus membranaceus*, *Bambusa vulgaris* sub. var. *green*, *Bambusa vulgaris* sub. var. *vittata*, and *Bambusa balcooa* were tested in experimental plots for their adaptability and growth performance at different locations in the country by the Forestry Directorate of the EIAR and the current EEFRI (Yigardu *et al.*, 2015). Currently, 16 bamboo species are maintained, managed, and multiplied in the compound of the Holeta Agricultural Research Center; however, large-scale testing for adaptability at different locations in the country is yet to commence. A second trial was initiated in Ethiopia in June 2016 using 13 bamboo species (*D. asper*, *D. yunnanensis*, *D. fuminensis*,

D. diannanensis, *D. membranaceus* var. *Grandis*, *D. peculiaris*, *D. barbatus*, *D. laosensis*, *D. sinicus*, *Bambusa longinternode*, *B. polymorpha*, *B. lapidea*, and *Phyllostachys pubescens*) from Yunnan, China, by the Ethiopian Ministry of Agriculture under its sustainable watershed management and livelihood improvement program. Currently, these species are in the nursery and establishment stage in five different districts (Bibugn, Arbegona, Bambasi, Wonchi Neader, and Adet) across the country.

Aiming at developing bamboo species-site suitability matching for the introduced bamboo species, a field inventory was performed and primary data on the growth characteristics and the ecological conditions required for the introduced bamboo species was collected from seven research plots and demonstration sites across Ethiopia. The inventory sites include Chagni (Awi zone, Amhara Region), Jimma (Jimma Zone, Oromia Region), Bishoftu (East Shewa Zone, Oromia Region), Tepi (Sheka Zone, SNNPR), Arbaminch University and Chano Mille (Gamo Zone, SNNPR), and Wondo Genet (Sidama Region). A total of eight species: *Bambusa vulgaris*, *B. bambos*, *B. balcooa*, *Dendrocalamus asper*, *D. hamiltonii*, *D. membranaceus*, *D. giganteus*, and *Guadua amplexifolia* were considered in the study (Table 9). This report thus presents the and growth characteristics and ecological conditions required for the studied species at the various study sites.

5.2 Site ecological conditions and growth characteristics of bamboo species introduced into Ethiopia

5.2.1. Site ecological conditions of introduced bamboo species in Ethiopia

In this study, the altitudes of the adaptation and demonstration sites ranged from 1,188 to 1,920 m.a.s.l. (Table 2). The lower site elevations (1,188, 1,197, and 1,200 m.a.s.l.) were recorded for the Chano Mille Nursery, Arbaminch University Nursery, and Tepi sites. Jimma and Chagni lie at higher altitudes than the aforementioned three sites, but with similar precipitation. The Chano Mille Nursery and Arbaminch University Nursery sites experience the highest maximum temperatures (36 °C), followed by Tepi (30 °C) and Chagni (28.6 °C). The highest altitude recorded was 1,920 m.a.s.l. at Wondo Genet, which receives the second lowest precipitation (1,372 mm) compared to all the other sites; the site with the least annual rainfall among the assessed sites is the Debre Zeit Nursery (980 mm).

Table 9. Geographic and agro ecological information and climatic conditions of the growing sites of exotic species.

S. No.	Name of experimental site	Administrative location of the experimental site			Species Tested	Latitude & Longitude	Altitude (m)	Climate (Average values)			Year of establishment
		District	Zone	Region				Mean Annual Rainfall (mm)	Max. Temp. (°C)	Min. Temp. (°C)	
1	Chagnii	Guangua	Awi	Amhara	<i>B. vulgaris</i> var. <i>green</i> , <i>D. membranaceus</i> , <i>D. hamiltonii</i> , <i>D. asper</i> and <i>G. amplexifolia</i>		1,700	1,725	28.6	13.2	2010
2	Jimma	Mana	Jimma	Oromiya	<i>D. membranaceus</i> , <i>D. hamiltonii</i> , <i>B. vulgaris</i> var. <i>green</i>	7° 46' N, 36° 00' E	1,753	1,530	26.2	11.3	2010
3	Debrezeit (Bishoftu)	Ada	East Shoa	Oromiya	<i>D. asper</i> , <i>B. balcooa</i> , <i>D. giganteus</i> , <i>D. hamiltonii</i>	08° 44' N, 38° 58' E	1,855	980	28.3	8.9	2010
4	Wondo Genet	Wondo Genet	-	Sidama	<i>D. asper</i> , <i>B. balcooa</i> , <i>D. hamiltonii</i> , <i>B. vulgaris</i> var. <i>vittata</i>	7° 19' N, 38° 38' E	1,920	1,372	26.2	11.5	2009
5	Tepi	Yeki	Sheka	SNNPR	<i>D. membranaceus</i> , <i>B. bambos</i> , <i>B. vulgaris</i> var. <i>green</i> , <i>D. hamiltonii</i>	7° 3' N, 35° 18' E	1,200	1,678	30	15	2012
6	Arba Minch University	Arbaminch Town	Gamo	SNNPR	<i>D. giganteus</i>	037° 34' N, 06° 04' E	1,197	1,725	36	23	2008
7	Chano Mille Nursery	Arbaminch Zuria	Gamo	SNNPR	<i>D. giganteus</i>	037° 36' N 06° 07' E	1,188	1,725	36	23	2004

Source: Field survey, 2020

5.2.2. Growth characteristics of introduced bamboo species in Ethiopia

Across the country, the number of species assessed varied from site to site (Tables 9). The DBH and culm height were dependent on the inherent characteristics of the species and on the growing conditions at the site.

Dendrocalamus asper

D. asper was tested at two sites (Chagni and Wondo Genet) and showed variations between the sites. Generally, however, this species showed superior performance at all the sites, with a DBH of 7.06–11.99 cm and culm height of 20–21 m. The growth performance also varied from clump to clump, which is primarily attributed to variations introduced by management practices such as heavily cutting part of the offsets from one clump to extract propagating materials and leaving other clumps intact. For instance, at Chagni, *D. asper* attained a maximum DBH of 10 cm in one undisturbed clump but recorded lower DBH values (7 cm) in other disturbed clumps. Generally, *D. asper* exhibited a similar DBH and culm height growth (average DBH of 14 cm and average height of 16 cm) to its typical growth performance at its origin, Southeast Asia (China).

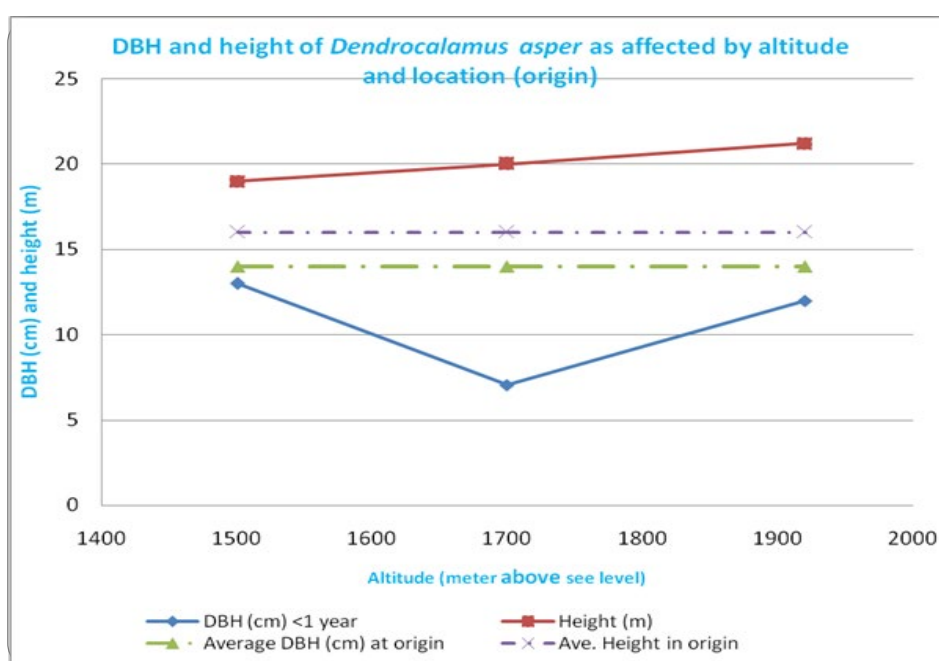


Figure 3. Growth performance (DBH and height) of *Dendrocalamus asper* along an altitudinal gradient in Ethiopia and between two global locations (Ethiopia vs. origin)

D. hamiltonii

Similarly, the performance of *D. hamiltonii* tested at three sites also varied from site to site, which may also be attributed primarily to factors at the sites and variances in management practices. The DBH and culm height of *D. hamiltonii* ranged from 7.2 cm to 8.4 cm and 16 m to 20 m, respectively, across sites. The performance of *D. hamiltonii* at one of the study sites (Chagni) was not included in this comparison because excessive removal of propagules for seedling production significantly affected growth. *D. hamiltonii* showed broadly similar DBH and culm height growth performance to its growth performance in its origin (Figure 3).

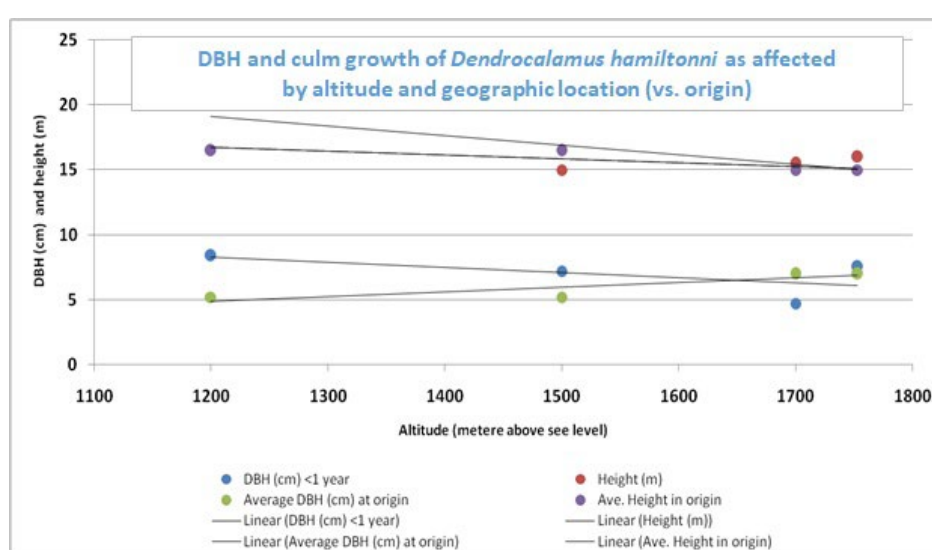


Figure 4. Growth performance (DBH and height) of *Dendrocalamus hamiltonii* along an altitudinal gradient in Ethiopia and between two global locations (Ethiopia vs. origin)

D. membranaceus and *B. vulgaris*

The DBH and culm height of *D. membranaceus* varied from 3.2 m to 7.3 cm and 12 m to 21 m, respectively, across sites. Compared to its growth performance at its origin (DBH: 17.5 cm, and culm height 12.5 m) in Southeast Asia, the DBH and culm height of *D. membranaceus* were lower in Ethiopia (Figure 4). This might be due to management and environmental factors. The DBH and culm height of *B. vulgaris* (3.5–8.17 and 13–15 m) can be considered comparable to the growth performance of the specie at its origin in Tropical Asia (DBH: 17 cm, and culm height: 15 m). The DBH and culm height of *D. membranaceus* and *B. vulgaris* varied considerably across the testing sites: 3.19 cm in Chagni vs. 7.3 cm in Tepi for *D. membranaceus*, and 2.58 cm in Chagni vs. 8.17 cm at Tepi for *Bambusa vulgaris* (Table 10).

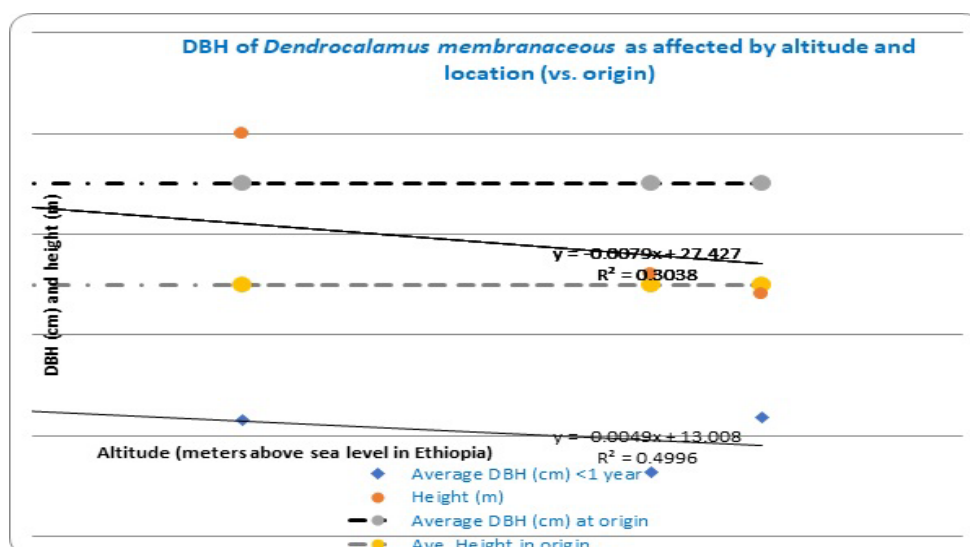


Figure 5. Growth performance (DBH and height) of *Dendrocalamus membranaceus* along an altitudinal gradient in Ethiopia and between two global locations (Ethiopia vs. origin)

D. giganteus

The DBH growth performance of *D. giganteus* (15.13 cm to 17.88 cm) was lower in Ethiopia compared to its growth performance in its origin (Myanmar/Burma, Bhutan, China, and Thailand); however, a similar height range (20 m to 24 m) was observed (Figure 5).

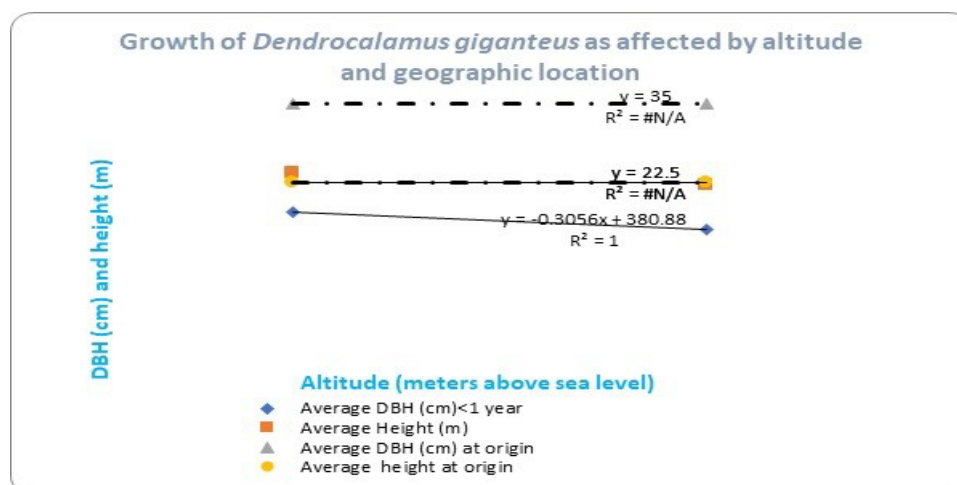


Figure 6. Growth performance (DBH and height) of *Dendrocalamus giganteus* along an altitudinal gradient in Ethiopia and between two global locations (Ethiopia vs. origin)

Bambusa bambos* and *B. balcooa

B. bambos performed well under the conditions at Tepi (DBH: 7.98 cm, and culm height: 16 m); however, from observations at Chagni and Pawe, its performance was poor and this data

was excluded from evaluations in this assessment. *B. balcoa* performed well under the conditions at Wondo Genet, but was not tested at any other sites.

Number of Culms Per Clump

The number of culms per clump varied among the species and sites. At the Chagni site, *B. vulgaris* green had the highest number of culms per clump (460), followed by *D. membranaceus* (422 culms per clump), (Table 2). *G. amplexifolia* had the least number of culms per clump (17) and a low survival rate under the conditions at Chagni.

Table 10. Growth characteristics values (average) of the introduced bamboo species across

S. No.	Research site	Species	Average DBH (cm)			Height (m)	No. of culms/clump
			<1 year	1–3 years	>3 years		
1	Arbaminch University Nursery	<i>D. giganteus</i>	15.13	11.13	7.34	22	44
2	Chagni	<i>B. vulgaris</i> var. <i>green</i>	2.58	2.12	2.44	10	422
3	Chagni	<i>D. membranaceus</i>	3.19	2.97	2.75	13	460
4	Chagni	<i>D. hamiltonii</i>	4.72	3.46	3.84	11+	95
5	Chagni	<i>D. asper</i>	7.06 (max.9)	6 (max.10)	6.69 (max.9)	20	214
6	Chagni	<i>G. amplexifolia</i>	7.1	-	4.88	13	17
7	Chano mile Nursery	<i>D. giganteus</i>	17.88	14.44	10.08	24	134
8	Jimma	<i>D. membranaceus</i>	5.9	4.59	4.19	12	190
9	Jimma	<i>D. hamiltonii</i>	7.53	5.28	4.54	16	225
10	Tepi	<i>D. membranaceus</i>	7.32	4.7	4.28	16+	191
11	Tepi	<i>B. bambos</i>	7.98	4.98	4.6	16+	170
12	Tepi	<i>B. vulgaris</i> var. <i>green</i>	8.17	5.47	4.72	15+	171
13	Tepi	<i>D. hamiltonii</i>	8.4	5.82	4.77	20	219
14	Wondo Genet	<i>D. asper</i>	11.99	7.26	5.63	21.2	58
15	Wondo Genet	<i>B. balcooa</i>	7.77	5.03	-	20	62

experimental sites

Source: Field inventory, 2020

6. Identification guide for bamboo species in Ethiopia

6.1 Introduction

Identifying the bamboo plant is a challenging task, primarily because of its long flowering intervals, which in some cases are up to 130 years. However, in traditional taxonomy, the components of the flower are often the most easily distinguishable part of a plant and is useful for classification purposes (Complete Bamboo, 2020). Identification of the bamboo plant has been a topic of debate for many years. The best way to identify bamboos depends upon the time available, botanical knowledge, and interest, as well as the accuracy required.

Notwithstanding the challenges attending bamboo identification, the easiest way to identify bamboos is to find good pictures that clearly show the characteristics essential for distinguishing them. However, the photographer or artist and the identifier need to know which specific parts of the plant are critical for identification, and these characteristics must be presented clearly. Photos of bamboos are in some case are remarkably similar, and it is crucial to make specific morphological characteristics of the bamboo plant particularly visible in the photos. For bamboo identification, close-up pictures showing culm nodes, culm sheaths, and leaf sheaths provide the greatest value.

In addition to photos, characteristics of the culm, branches, culm sheaths, leaf blades, and the young shoot are used to species. This guide is prepared both for indigenous and introduced bamboo species with the objective of helping development practitioners to easily and quickly identify specific bamboo species.

6.2. Description of introduced bamboo species available in literature

6.2.1. *Dendrocalamus asper* (Schult.) Backer

Dendrocalamus asper, also known as Rough Bamboo or Giant Bamboo, is a giant tropical and subtropical dense clumping species native to Southeast Asia (Guadua Bamboo, 2020). This timber bamboo is used as a building material in heavy construction and its shoots are consumed as a vegetable. Its description is as follows:

- Densely tufted, sympodial bamboo.
- The culm is erect, with a pendulous tip; 20–30 m tall, with a diameter of 8–20 cm near the base, and a wall 11–36 mm thick that is sometimes almost solid at base. The culm has internodes 10–20 cm (lowermost) to 30–50 cm or more (upper ones) long, which

are white waxy below the nodes. The nodes are swollen, with the lowest nodes bearing many aerial roots.

- There are branches arising from the mid-culm nodes upwards, with few at each node and the primary branch is dominant.
- The culm sheath is 20–40 cm × 20–25 cm, covered with dark brown to pale brown hairs. Its blade lanceolate is at first erect and later deflexed. The ligule is approximately 10 cm long and its auricles are prominent, bearing slender bristles along the edges.
- Young shoots covered with dark brown to black hairs.
- Leaf blade of 30 cm × 2.5 cm, with sheath glabrous or scattered pale hairs; ligule is very short; auricles are absent.

The species is also described in the Flora of China, as follows: culms are 15–20 m tall and 6–12 cm in diameter; internodes are 30–50 cm. Branches from approximately at the 9th node up, and central branch is dominant.



Figure 7. Clump of *Dendrocalamus asper*

6.2.2. *Dendrocalamus giganteus* Munro

Dendrocalamus giganteus is one of the tallest bamboo species in the world. The bamboo is known as Giant Bamboo or Dragon Bamboo. Its description is as follows:

- Densely tufted, sympodial, giant bamboo.
- Culm is erect, with arching tip. Up to 30 m tall, 18–25 cm in diameter near the base, and the wall is up to 25 mm thick. Covered in a white waxy layer when young, which

becomes smooth and whitish to grayish green as it ages. Internodes are 25–55 cm long, lower shortest nodes are not swollen, with lower nodes bearing aerial roots.

- Branches arising from mid-culm nodes, comprising one dominant branch and several smaller branches.
- Culm sheath of 25–50 cm × 25–50 cm, widest at lower internodes, with dark brown hairs on the back. Spreading blade, broadly triangular (on lower sheaths) to narrowly triangular, 13–38 cm × 9 cm. Ligule is 8–12 mm long, stiff, and shortly fringed. Auricles are crisp, 1.5 cm × 3 mm, brown, and not bristly.
- Young shoots are purplish.
- Leaf blade is oblique-oblong, 20–40 cm × 3–7 cm, glabrous, and slightly rough. Ligule is 2–3 mm long and irregularly toothed. Auricles are small and glabrous.



Figure 8. Clump of *Dendrocalamus giganteus*

6.2.3. *Bambusa vulgaris* Schrad. ex J. C. Wendl. var. *vittata*

Bambusa vulgaris 'Vittata' (Painted Bamboo) is a large tender clumping bamboo with a maximum height of 15 m under optimum conditions. It has large arching golden-yellow culms, which have green vertical stripes that look like drip marks, and the branches are often striped. As described in PROSEA:

- Open, not closely tufted, sympodial bamboo.
- Culm is erect, slightly zig-zag, 10–20 m tall, and 4–10 cm in diameter, with a 7–15 mm thick wall that is glossy green, yellow, or yellow with green stripes.

- Internodes are 20–45 cm long, with appressed dark hairs. White and waxy when young; becoming glabrous, smooth and shiny with age. The nodes are oblique and slightly swollen; the basal nodes are covered with aerial roots.
- Branches arise from the mid-culm nodes upward, and are occasionally also at lower nodes, with several to many at each node. Primary branch is dominant.
- Culm sheath is more or less broadly triangular and 15 × 20 cm to 45 × 20 cm. Upper culm sheaths are longest, deciduous, and light green. Young shoots are yellow green and covered with black hairs. Leaf blade is 6 × 1 cm to 30 × 4 cm and glabrous. Ligule is a sub with the entire rim 0.5–1.5 mm long. Auricles with small, rounded lobes 0.5–1.5 mm long and a few bristles 1–3 mm long.



Plate 7a: *Bambusa vulgaris* ' var. vittata stand (Wondogenet)



Plate 7b: *Bambusa vulgaris* ' var. vittata stand with leaf (Wondogenet)

Figure 9. Stands of *Bambusa vulgaris* var. *vittata*

6.2.4. *Bambusa balcooa* Roxb

Bambusa balcooa species stands as the best species among others of genus *Bambusa*, with its thickest and largest robust culms being highly prized and widely used in the construction of houses and various other frameworks, and in basket and mat making (Saikat *et al.*, 2015).

Bambusa balcooa, as described in PROSEA (2020):

- A densely tufted, sympodial bamboo.
- Culm is erect with pendulous tip, 17.5 m tall, 2.5–10 cm in diameter near the base, with a wall more than 20 mm thick, and dirty silvery-brown pubescent. Internodes are 20–45 cm long, and the 6th–8th internodes are generally the longest. The lower nodes

bear aerial roots; above and below the nodes, there is a circular band of fine whitish-brown hairs.

- Branches arising from all nodes, with branches from the lower nodes bearing no leaves. Branches are small and, sometimes, recurved and thorn like.
- Culm sheath is 15 × 15 cm to 35 × 40 cm, and are much shorter and wider at with lower nodes than at upper nodes; deciduous and green when young and covered with blackish-brown hairs on the back. Ligule is membranous, 5–8 mm long, and denticulate. Auricles are absent or very small, and ciliated.
- Young shoot is blackish green and covered in blackish hairs. Leaf blade is oblong-lanceolate, 15 × 2.5 cm to 30 × 5 cm, and glabrous.



Figure 10. Growing *Bambusa balcooa* clump at Wondogenet

6.2.5. *Dendrocalamus hamiltonii* Nees and Arn ex Munro

Dendrocalamus hamiltonii as described in PROSEA (2020).

- Culm is up to 25 m tall, with diameter of 10–20 cm; relatively thick-walled; grayish-white when young, becoming green at maturity.
- Culm sheath is usually glabrous, with a truncated top; blade is ovate to lanceolate; auricles are small, without bristles.
- Leaf blade is 20 × 4 cm to 30 × 6 cm; ligule is conspicuous; and auricles are absent.

Dendrocalamus hamiltonii as described in Flora of China (2020):

- Culms are 12–18 m tall, 9–13 cm in diameter, and are often very pendulous; internodes are 30–50 cm, scurfy and persistently densely white to brown; wall is 1.2–2 cm thick.

- Branches several in number, with a very well developed dominant central branch, especially on older pendulous culms on which branches can approach the size of the culm.
- Culm sheaths are deciduous, initially with patches or stripes of dark brown hairs, the margins are ciliated and the apex is slightly arched; auricles are absent; ligule is 1–3 mm.
- Leaf sheaths are yellow and setose; ligule is 1.5–2 mm; blades are variable, largest ca. 38 × 7 cm.



Figure 11. *D. hamiltonii* stand at Piccolo Abbai in Amhara Region

6.2.6. *Guadua amplexifolia* J. Presl.

Guadua amplexifolia as described in PROSEA (2020):

- A densely tufted, sympodial bamboo.
- Culm erect with pendulous tip 5–30 m tall (average: 17.5 m), 2.5–10 cm in diameter near the base; wall more than 2 cm thick with dirty silvery-brown pubescent.
- Internodes 20–45 cm long, 6th–8th internodes are generally the longest, nodes are swollen, with a supranodal ridge; lower nodes bearing aerial roots above and below the nodes, with a circular band of fine whitish-brown hairs.
- Branches arising from all nodes, those from the lower nodes bearing no leaves, small and sometimes recurved and thorn like.
- Culm sheath 15 × 15 cm to 35 × 40 cm, much shorter and wider in lower nodes than in upper nodes, deciduous, green when young, covered with blackish-brown hairs on the back; blade are triangular and erect at 6 × 5 cm to 8 × 7 cm. Young shoot is blackish green; covered with blackish hairs.

- Leaf blade is oblong-lanceolate, 15 × 2.5 cm to 30 × 5 cm, glabrous, with ciliated margin.



Figure 12. *G. amplexifolia* stand (Tepi, Ethiopia)

6.2.7. *Bambusa bambos* (L.) Voss

Bambusa bambos is a multipurpose bamboo with uses ranging from edible shoots (vegetable), leaves (forage), and seeds (famine food) to valuable culms for household uses and as basic construction materials. *Bambusa bambos* is often planted as windbreaks around farms and along rivers to check floods. The specie is described in PROSEA (2010) as follows:

- Densely tufted, sympodial bamboo.
- The Culm is erect, up to 30 m tall and 15–18 cm in diameter, wall is very thick and is sometimes almost solid in the upper part of the culm and distal parts of the branches.
- Internodes are usually 20–40 cm long and bright green; nodes are slightly swollen, with the lower ones sometimes having aerial roots.
- Branches develop from all nodes, with the lower branches spreading in a spine-like manner, bearing recurved spines and forming a dense nearly impenetrable thicket in the lower part of the clump. The upper leafy branches are horizontal or ascending, bearing small spines or spineless. Branches also develop as spine branches.
- Culm sheath is 15 × 18 cm to 35 × 30 cm, coriaceous, and wrinkled at the top, brown and hairy when young glabrous when old, deciduous at the time branches develop.
 - ✓ Ligule is continuous with the sheath top, 2 mm long, white, and ciliated.
 - ✓ Blade is more or less reflexed, much shorter than the sheath, triangular, with a broad sloping and wrinkled base on either side (constituting the auricles).
- Leaf blade is lanceolate to linear, 6 × 1 cm to 22 × 3 cm, and glabrous; ligule short, entire; auricles small, bearing a few bristles.

6.3. Description of Indigenous Species

6.3.1. Highland bamboo (*Oldeania alpina*)

In Useful Trees and Shrubs of Ethiopia, *Arundinaria alpina* is described by Bekele (2012) as a large hollow-stemmed grass, usually 6–8 m but can reach 12–25 m. The stems (culms) are smooth, woody, hollow, yellowish green to brown, growing from swollen underground stems (rhizomes). Whorls of thin branches grow at the thickened upper nodes, and stems can reach 7–10 cm in diameter.

The leaves grow from branchlet nodes, pale green, up to 20 cm long and 1 cm wide, the tip long and thin; rough to the touch because of short hairs. Leaves appear from a large yellow leaf sheath to 50 cm long, with purple hairs. The flowers are rarely seen, and grow in heads 10–20 cm long. After flowering the plant dies down.



Plate 12a: *O. alpina* culm sheath



Plate 12b: *O. alpina* culm with culm sheath



Plate 12c: *O. alpina* stands (Hula District)

Figure 13. *Oldeania alpina* stands (Hula District)

6.3.2. Lowland bamboo (*Oxytenanthera abyssinica*)

In Flora of Ethiopia and Eritrea (volume 7) by Sylvia (1995), *Oxytenanthera abyssinica* is described as: clump-forming bamboo with woody culms that are erect or ascending, 3–13 m high, 5–10 cm in diameter, nearly solid, and initially silky-pubescent.

Culm sheaths are hispid, with brown hairs; lacking auricles; and tipped with an involute pungent blade 1–2 cm long. Leaf blades are narrowly lanceolate-oblong, 10–26 cm long and 1.8–3 cm wide, inconspicuously cross-veined, and base is broadly rounded, with a brief petiole-like connection to the sheath and a tip that is finely acuminate; leaf sheaths bearing a few deciduous setae on the shoulders.

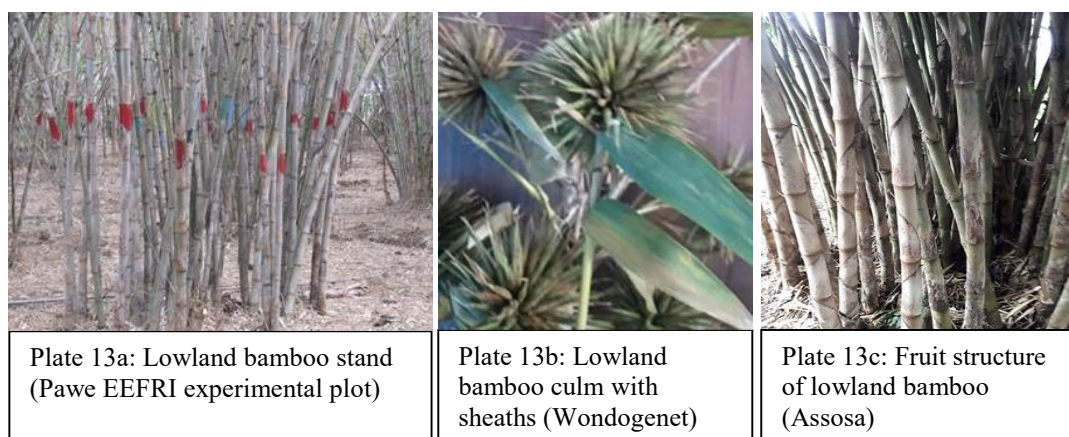


Figure 14. Lowland bamboo stand, culm with sheath and fruit structure

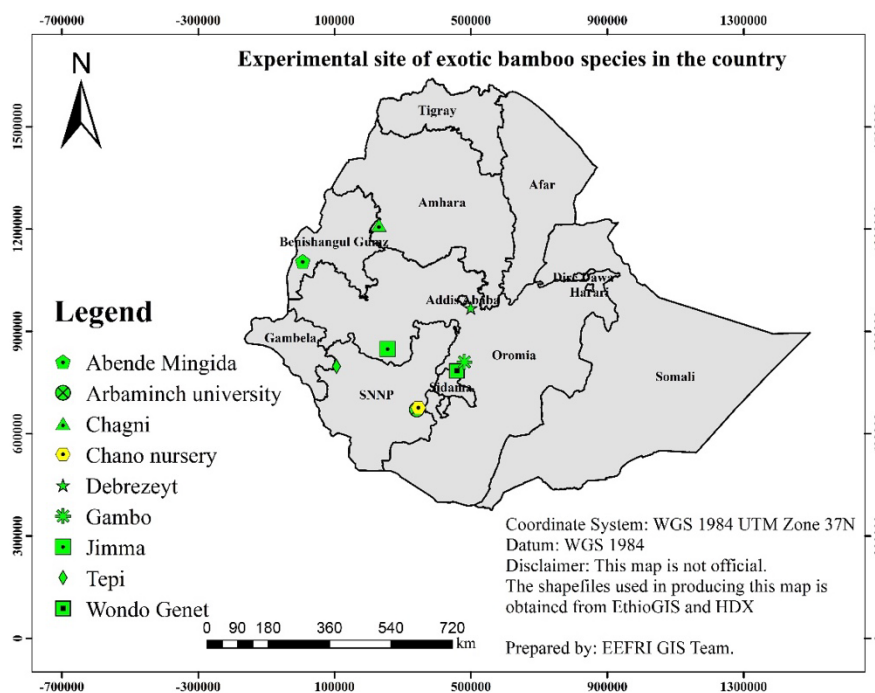


Figure 15. Experimental sites of introduced exotic bamboo species across the country

7. Bamboo species-site suitability matching

7.1. Criteria used to define bamboo species-site matching maps

Geographic, climate, and soil data were collected during the field assessment conducted in this study. Because this survey could not be exhaustive, previous reports—primarily MEFCO (2018) and INBAR (2018)—were also consulted regarding suitability to promote the two native bamboo species. Considering the data, criteria were set for classifying a site both in the studied regions and districts and elsewhere in Ethiopia to be either suitable or unsuitable for the two species. The environmental conditions under which the lowland and highland bamboos can grow are presented in Table 11. On this suitability matching list, a certain weight has been assigned to each selected criterion, and all involved factors are assigned the same weight as equal contributors to the overarching multivariate analysis. Thus, the influence captured on the resulting suitability map is from all factors.

Table 11. Environmental attributes required for highland and lowland bamboo plantation grouped under two suitability classes

Factor/ Criterion	Unit	Highland bamboo	Lowland bamboo
		Suitable	Suitable
Temperature	Degree Celsius	10–21	17–35
Rainfall	mm/year	>900	>500
Elevation	Meters	2200–3500	500–1900
Slope	Percent	0–60	0–45

In addition to the information presented in Table 11, land use classification was also considered in the suitability analysis for both highland and lowland bamboo species. Land use classes categorized as suitable include sparse and moderate forest, cropland, shrub land, woodland, and bare soil. In contrast, considered unsuitable for bamboo plantations are land use classes such as dense forest, wetland, lava flow, saltpan, water body, and settlement.

Table 12. Suitable areas for indigenous bamboo species plantation in Ethiopia

Region Name	Suitable Area				Grand Total (Ha)
	Highland bamboo		Lowland bamboo		
	Area (Ha)	%	Area (Ha)	%	
Addis Ababa	14,360.35	26.63	0.00	0.00	14,360.35
Afar	0.00	0.00	2,591,224.08	27.43	2,591,224.08
Amhara	4,129,361.80	26.60	6,880,238.83	44.32	11,009,600.63
Benishangul-Gumuz	39,275.94	0.79	4,650,904.85	93.12	4,690,180.79
Dire Dawa	273.93	0.26	95,214.98	90.22	95,488.92
Gambela	109.64	0.00	741,686.06	24.70	741,795.70
Harari	0.00	0.00	25,294.07	68.07	25,294.07
Oromia	4,533,229.30	14.05	19,281,377.66	59.76	23,814,606.95
Sidama	210,706.81	31.11	281,405.76	41.56	492,112.57
SNNP	866,270.30	8.54	5,663,778.66	55.83	6,530,048.96
Somali	0.00	0.00	5,034,991.08	16.22	5,034,991.08
Tigray	86,677.24	1.68	3,286,522.07	63.56	3,373,199.31
Grand Total	9,880,265.30	109.66	48,532,638.10	43.15	58,412,903.40

Bamboo Suitability Maps

Two national maps showing suitable independent national areas for each species are presented in Fig 24 and Fig. 25. As the national maps indicate, the suitable areas are located in seven regions and city administrations, some of which currently have bamboo growing within their borders, while others have huge potential (Benishangul-Gumuz, Oromia, Amhara, SNNPR, Sidama, Gambela, the western part of Tigray, and in small parts of Somali, Afar, and Harari).

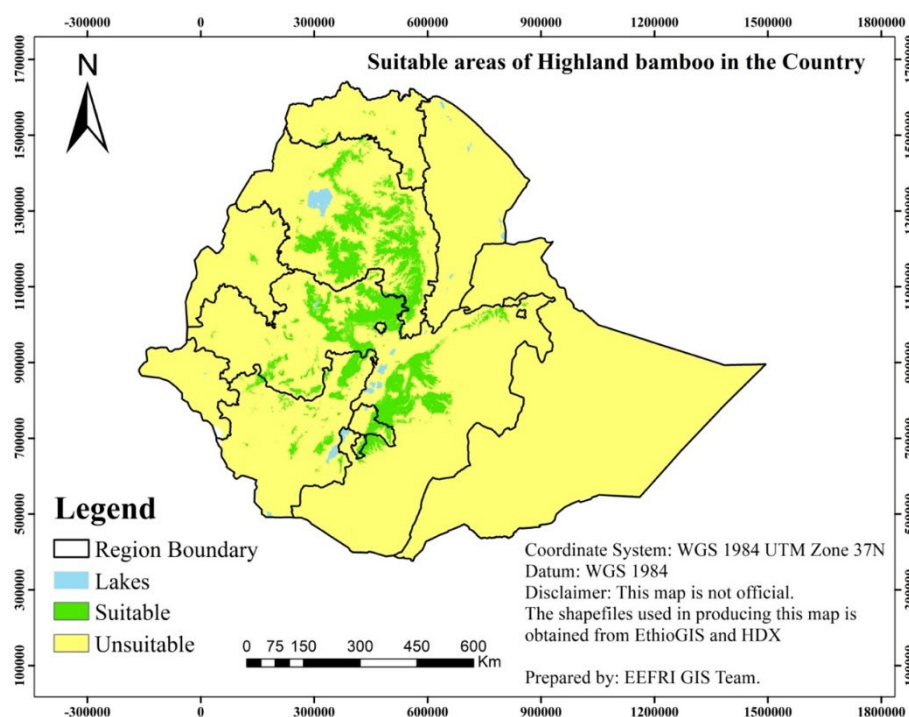


Figure 16. Map of suitable areas for highland bamboo plantation in Ethiopia

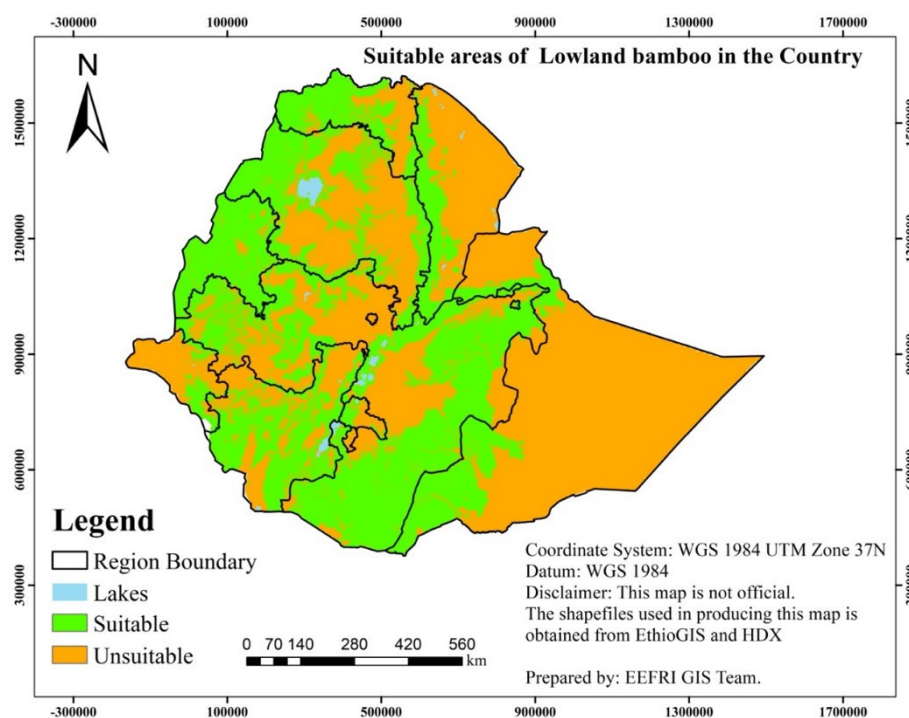


Figure 17. Map of suitable areas for lowland bamboo plantation in Ethiopia

8. Conclusion and recommendations

The altitudinal range of the eight study sites for highland bamboo lies between 2,387 and 2,979 m.a.s.l., with annual rainfall of between 1,200 mm and 3,000 mm. The average DBH of highland bamboo ranges between 4.7 cm and 8.2 cm, and the average height ranges between 10.3 m and 15.0 m. The average internode length of highland bamboo at a height of 1.3–3 m ranges from 33.2 cm to 71 cm.

The altitude of the eleven lowland bamboo-growing sites studied range from 1,110 to 1,765 m.a.s.l. Two of the highest elevation sites (one of them receiving the highest rainfall and low temperatures) recorded significantly high bamboo growth performance from seedlings originated from seeds. The slope of the study sites ranges from 5% to 60%. Average DBH of culms for the sites is 4.4 cm, 3.7 cm, and 3.6 cm for culms aged <1, 1–3 and > 3 years, respectively. Average height ranges from 5.5 m to 12 m. A decrease in DBH as plant age increases was observed in this study, and it can be attributed to the young age of the stands on the one hand and challenges stemming from stand management on the other hand. The three highest records for number of culms per clump were 59, 57, and 56, while the lowest was 14.

The assessment results for introduced bamboo species indicates that *Dendrocalamus asper* (DBH: 7.06–11.99 cm, and culm height: 20–21 m), *Dendrocalamus hamiltonii* (DBH: 4.7–8.4 cm, and culm height: 11–20 m), *Dendrocalamus giganteus* (DBH: 15.13–17.88 cm), *Bambusa vulgaris* var. green (DBH: 3.5–8.17 cm and culm height 13–15 m) have promising growth performance and a wide recommended domain that is similar to the experimental sites. In contrast, *Guadua amplexifolia* (DBH: 7.1 cm, and culm height: 13 m), *Bambusa bambos* (DBH: 7.98 cm, and culm height 16 m), and *Bambusa balcooa* (DBH: 7.77 cm, and culm height 20 m) were tested at only one site. *Guadua amplexifolia* and *Bambusa balcooa* performed well at the experimental sites and were found to be promising for areas similar to the experimental sites. Number of culms per clump varied among species and across sites. *B. vulgaris* green has the highest number of culms per clump (460), followed by *D. membranaceus* (422 culms per clump). *G. amplexifolia* has the least number culms per clump (17) and a low survival rate at one site.

In this study, an identification guide for nine—two native and seven introduced—bamboo species is produced using close-up pictures that clearly show the critical characteristics for

distinguishing between these species, e.g., culm nodes, culm sheaths, leaf sheaths, culm, branches, leaf blade, and the characteristics of young shoot.

8.1. Recommendations

Highland Bamboo

Highland bamboo is an economically important species native to the highland areas of Ethiopia. It is found both as natural forests and as plantations. In this study, 15 sites across the country were assessed to investigate the ecological characteristics and growth conditions required for these species. It was found to perform well at all the assessed sites located at an elevation of >2,300 m.a.s.l., and thrives at up to 3,500 m.a.s.l with a mean annual rainfall of >1200 mm and in temperatures varying between 6 °C and 30 °C.

Lowland Bamboo

Lowland bamboo is more localized in its distribution across the west and northwestern parts of Ethiopia. It has aggressive growth and high productive potential, provided silvicultural management practices (protection, spacing, and weeding) are implemented. Notwithstanding variations in its growth performance, which is linked to a lack of proper management, the species was found to exhibit more or less good growth at the studied sites, with an altitudinal range of 1,100 m.a.s.l. to 1,765 m.a.s.l. and a slope of 5–60%. The species grows well with an annual rainfall of >500 mm and an annual temperature range of 17 °C to 35 °C.

Information on the natural ecological distribution and domestication areas in this study and the recorded growth performance of bamboos in the corresponding sites strongly indicate that lowland bamboo can be cultivated at higher elevations, e.g., the Abdi Teklu Plantation and Wondo Genet sites. The recorded performance of bamboo in its natural range, e.g., Guder-Kava (Jawi), strongly indicates that lack of management during the early regeneration stage reduces the growth performance of lowland bamboo.

Exotic Bamboos

Ethiopia introduced different bamboo species from Southeast Asia and South and Central America. Site conditions where the exotic bamboo species were evaluated vary considerably in geographic location and climatic conditions such as rainfall and temperature. Generally, however, the results of the assessment indicate that *Dendrocalamus asper*, *Dendrocalamus hamiltonii*, *Dendrocalamus giganteus*, and *Bambusa vulgaris* var. green have wider

adaptation. In contrast, *Guadua amplexifolia*, *Bambusa bamboos*, *Bambusa balcooa* and *Bambusa vulgaris* var. *vittata* have also shown good performance at limited tested sites.

References

- Alemayehu, A., Mulatu Y., Eshete N. and Asmare, M.T. (2015) 'Growth Performance and Biomass Accumulation of Four Different Introduced Bamboo Species in South-Western Ethiopia', *Journal of Biology, Agriculture and Healthcare*, 5(3), p116-122.
- Brias, V. Hunde, T and Juergen H. (2009) Bamboo Cultivation Manual Guidelines for Cultivating Ethiopian Highland Bamboo: *Eastern Africa Bamboo Project*, Addis Ababa, UNIDO: p. 58.
- Bystriakova, N., Kapos, V., Stapleton, C. and Lysenko, I. (2003) *Bamboo Biodiversity: Information for Planning Conservation and Management in the Asia-Pacific Region*. Cambridge: UNEP-WCMC and INBAR, p. 1-72.
- Canavan, S., Richardson, D. M., Visser, V., Le Roux, JJ., Vorontsova, M.S. and Wilson, J.R.U. (2017) 'The Global Distribution of Bamboos: Assessing Correlates of Introduction and Invasion', *AoB PLANTS*, 9(1), p1-18.
- Complete Bamboo (2012) Bamboo information resource [online]. Available at: http://www.completebamboo.com/about_complete_bamboo.html
- Ceulemans R, McDonald A, and Pereira J. (1996) 'A comparison among eucalypt, poplar and willow characteristics with particular reference to a coppice, growth-modelling approach', *Biomass and Bioenergy*, 11(2-3), p215–231.
- Getahun A., Kebede Y, Tadese Z., Jebiso G., Alemu M., Azene B., Mulatu Y., Berhane K. and Getent A. (2019) *Effects of harvesting intensities on yield production of Yushania alpina (K. Schum.) W.C.Lin. (Ethiopian highland bamboo) in Ankeshia-guagussa, North-west Ethiopia*. EEFRI Report.
- Hytönen J. (1994) 'Effect of cutting season, stump height and harvest damage on coppicing and biomass production of willow and birch', *Biomass and Bioenergy*, 6(5), p349-357.
- Islam, S., & Banik, S., (2005) 'Leaf dynamics and above ground biomass growth in *Dendrocalamus longispathus* Kurz', *Journal of Bamboo and Rattan*, 4(2), p143-150.
- INBAR. (2015) *Bamboo for Africa: A strategic resource to drive the continent's Green Economy*. Available at: <http://www.inbar.int/sites/default/files/resources/>.
- INBAR. (2018) *Remote Sensing-Based Regional Bamboo Resource Assessment: Ethiopia, Kenya and Uganda*. INBAR Technical Report, p. 46.
- INBAR. (2018) *Value chain analysis and market assessment of bamboo products*. INBAR working paper.
- Kleinhenz, V. and Midmore, D.J. (2001). 'Aspects of Bamboo Agronomy', *Advances in Agronomy*, 74, p99-153.

- Kelbessa E., Bekele T, Gebrehiwot A. and Gebremedhin H. (2000) *A socio-economic case study of the bamboo sector in Ethiopia: An analysis of the production-to-consumption system*. INBAR Working Paper, p. 41.
- Kigomo, B. N. (2007) *Guidelines for Growing Bamboo*. KEFRI Guideline Series: No. 4. Nairobi: Kenya Forestry Research Institute.
- Kowit S., Wanida S., Prachoen S. and Suthep C. (2001) Review of bamboo management. Internal Technical Report no 1, Project: FD 56199 Rev. I (1)
- Kristina, L.C. and Juan, I.A. (2013) 'Specialization of bamboo by Neotropical Birds', *The Condor*, 115(2), p217-220.
- Lobovikov, M., Paudel S, Piazza M, Ren H and Wu. J. (2007) 'World bamboo resources: A thematic study prepared in the framework of the Global Forest Resources, assessment 2005', *FAO Technical Papers. World bamboo resources (fao.org)*
- LUSO, Consult GmbH. (1997) Study on Sustainable Bamboo Management (Final report). Hamburg.
- Mera, F. A. T. and Xu, C. (2014) 'Plantation Management and Bamboo Resource Economics in China', *Ciencia y Tecnologia*, 7(1), p1-12.
- Mulatu, Y., Alemayehu, A. and Tadesse, Z. (2016) *Biology and Management of Indigenous Bamboo Species of Ethiopia*.
- Mulatu, Y. and Fetene, M. (2013) 'The Effect of Silvicultural Management on Regeneration, Growth and Yield of *Arundinaria alpina* (Highland bamboo) at Choke Mountain, East Gojam, Northwest Ethiopia', *Ethiopian journal of agricultural science*, 27(July), p11-27.
- Nigatu A., Menale W., Asmamaw A., Dagnachew G. and Workagegnehu H. (2020) 'Productivity of highland bamboo (*Yushania alpina*) across different plantation niches in West Amhara, Ethiopia', *Forest Science and Technology*. Taylor & Francis, 0(0), p1-7.
- PROTA. (1989) *Sinarundinaria alpina* (K. Schum.) C.S. Chao and Renvoize. *Plant Resources of Tropical Africa*. Kew Bull, (44), p361.
- PROSEA (2020) Plant Resources of South-East Asia. Available at: <https://www.nhbs.com/3/series/prosea-plant-resources-of-south-east-asia>
- Seyoum, G., Lemma, T. and Yigardu, M. (2018) 'Indigenous knowledge on highland bamboo (*Yushania alpina*) management and utilization practices in Kokosa District, South East Ethiopia', *Scientific Research and Essays*, 13(11), p111-122.
- Seyoum, K., Tahir, P., Ding, W. and Sudin, R. (2007) 'Influence of bamboo age, board density, and particle size on performance of particleboard made from Ethiopia highland bamboo (*Yushania alpina*)', *Journal of bamboo and rattan*, 6(4), p239-250.

- Shultz. A. (2007) Can the season of burning affect the growth of *Dichrostachys cinerea* populations? A hypothesis of phenology. Honors thesis. University of Cape Town, South Africa
- Teshome K. (2015) 'Review of bamboo value chain in Ethiopia', *International Journal of African Society Culture and Traditions*, 2(3) p52-67.
- Tinsae B., Berhane, K., Ayelech, A., Yigardu, M. and Demelash, A. (2012) Effects of Germination Sites on Germination Percentage, Germination Energy and Germination Value of Lowland Bamboo Seeds, Proceedings of The National Workshop on Forestry Research Technologies Dissemination 29-31 May 2012, Hiruy Hall, EIAR, Wubalem Tadesse, GetachewDesalegn and Abraham Yirgu (eds.), Addis Ababa, Ethiopia.
- Victor, B. and Tesfaye H. (2009) *Guidelines for cultivating Ethiopian lowland bamboo*. Bamboo cultivation manual. Eastern Africa Bamboo Project.
- Wang, X. (2006) *Comparative Analysis and Policy Recommendations on Developing Bamboo Resource Tenure Systems in Asia and Africa*. Beijing: INBAR.
- Yigardu, M., Asabeneh, A. and Zebene, T. (2019) *Biology and Management of Indigenous Bamboo Species of Ethiopia Based on Research and Practical Field Experience*. Addis Ababa: Ethiopian Environment and Forest Research Institute.
- Zhou, B.Z., Fu, M.Y., Xie, J.Z., Yang, X.S. and Li, Z.C. (2005) 'Ecological functions of bamboo forest: Research and Application', *Journal of Forestry Research*, 16(2), p143-147.



www.inbar.int

@INBAROfficial