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Technical Paper

Bamboo Seed Sourcing / Selection Study in Ethiopia

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RESEARCH PROGRAM ON Forests, Trees and Agroforestry
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The International Bamboo and Rattan Organisation (INBAR) is an intergovernmental organisation dedicated to the promotion of bamboo and rattan for sustainable development. For more information, please visit www.inbar.int.

About this Working Paper

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List of Abbreviations

AFE	Amhara Forest Enterprise
BG	Benishangul Gumuz
C	Centigrade
CEE-FRC	Central Ethiopia Environment and Forest Research Center
Cm	Centimetre
E	East
N	North
INBAR	International Bamboo and Rattan Organisation
DBH	Diameter at Breast Height
EEFRI	Ethiopian Environment and Forest Research Institute
EIAR	Ethiopian Institute of Agricultural Research
GPS	Geographic Positioning System
Ha	Hectare
SNNPRS	South Nations, Nationalities and People's Regional State
PARC	Pawe Agricultural Research Center
MASL	Meter Above Sea Level
Max.	Maximum
Min.	Minimum
MIP	Material Import Permit
MTA	Material Transfer Agreement
MoA	Ministry of Agriculture
M	Meter
Mm	Millimetre
EBI	Ethiopia Biodiversity Institute
SLMP	Sustainable Land Management Program
EFCCC	Environment, Forest and Climate Change Commission
NFSDP	National Forest Sector Development Program

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Executive summary

Ethiopia has one of the largest bamboo resources in Africa, with an estimated 1.47 million ha (INBAR, 2018a) of two indigenous bamboo species, *Oxytenanthera abyssinica* and *Oldeania alpina syn. Yushania alpina* or *Arundinaria alpina*. The country has also introduced more than 23 exotic bamboo species, among which *Dendrocalamus asper, Dendrocalamus hamiltonii, Dendrocalamus membranaceus, Bambusa balcooa, and Bambusa vulgaris (*green) are found performing well in different agro climatic zones. The country has a national bamboo strategic plan that aims to promote bamboo plantations and enhance their utilization. However, lack of bamboo planting material of required species, in required quantity and quality has always been a challenge due to the flowering nature of bamboo and lack of standardized selection and propagation protocols. This technical manual is, therefore, prepared to guide bamboo seed sourcing in the country.

This study was done in five woredas[1] selected from five widely bamboo regions of Ethiopia: Benishangul Gumuz, Amhara, Oromia, Southern Nation Nationalities and Peoples' and Sidama regions. In each study woreda, three sample sites were selected based on their bamboo coverage and performance, and one representative sample plot of 20 m × 20 m (400 m^2) was established in each selected site. Growth parameters, such as density, culm diameter and culm height, were assessed by categorising bamboo culms into three age classes (<1 year, 1–3 years and >3 years). Geographic information was recorded and climate data were investigated against growth parameters. The reproductive biology of the species was studied, and seed processing and seed handling protocols were developed.

The relatively good performance of lowland bamboo at higher altitudes of 1700 and 1765 masl indicates that lowland bamboo performs well even at higher elevations that may extend to 2000 masl in contrast to 700/1800 masl, which is often stated as a higher elevation margin for the species. The increasing trend of diameter at breast height (DBH) growth against temperature of the studied sites indicates that growth of lowland bamboo is higher in areas that receive lower average annual temperature (minimum 10.7ºC and maximum 25.3°C) as compared to the literature that indicates the mean temperature requirements of the species to be between 20 and 35°C. Thus, promoting lowland bamboo in lower minimum temperature areas (as low as 10.4ºC) is recommended.

[1]*Woreda, Amharic word, meaning administrative unit equivalent to "district"*

Generally, in this study, highland bamboo showed an increase in DBH growth as altitude increased from 2387 masl to 2979 masl with higher annual temperature values (average min. 8.2°C, and average max. 23.1°C) and annual rainfall of 1123 - 2144.61 mm. Literature indicates that annual rainfall requirement of highland bamboo from 800 mm in Tanzania to 1400-2000 mm in Ethiopia and 3000 mm in Cameroon (Phillips, 1995; PROTA, 1989).

The introduced species *D. asper* shows generally similar DBH and height growth in Ethiopia as compared to is growth in its origin. DBH and height of *D. hamiltonii* ranged from 7.2 cm to 8.4 cm and 16 to 20 m, respectively, across the studied sites in Ethiopia which are even better values as compared to growth of the species in its area of origin (DBH 5.2 cm and height of 16.5m). As compared to its growth in its origin (DBH 17.5 cm and height 12.5 m), Southeast Asia, DBH and height growth of *D. membranaceus* is lower in Ethiopia. The DBH growth of *B. vulgaris* (3.65 - 8.17 cm) is also lower in Ethiopia as compared to its growth in its origin (17 cm). However, growth interms of height of of *B. vulgaris* (13-15 m) in Ethiopia is comparable to its growth in its origin (15 m). DBH growth of *D. gigantues* (15.13 to 17.88 cm) is lower in Ethiopia as compared to its growth in its origin (Myanmar, Burma, Bhutan, China and Thailand), although records of height growth are similar (20 to 24 m). Generally, the results of the assessment indicate that *Dendrocalamus asper, Dendrocalamus hamiltonii, Dendrocalamus giganteus* have shown superior performance in Ethiopia in reference to their growth in their areas of origin. *Bambusa vulgaris* and *D. membranaceus* have wider recommendation domains in Ethiopia that is similar to the studied sites, whereas *Guadua amplexifolia, Bambusa bambos* and *Bambusa balcooa* were tested only on one site, which narrows the recommended domains of the species.

Highland bamboo flowers less frequently, with a flowering cycle of about 45 to 50 years. During the last two decades, it has been flowering gregariously and sporadically in different administrative zones of Southern Ethiopia, including Dawro, Gedeo, Masha, and Keffa. An assessment and discussion held with the community in the Keffa zone in August 2020 indicated that highland bamboo develops inflorescence during October and November; shedding of inflorescence and fruit initiation stages happen in December and January, followed by seed development or fruiting in the consequent months. June and July are the months for full maturity of seeds. August to November is the time for collecting matured seeds for seedling production purposes. Seed collection and processing protocol for Ethiopian highland protocol is developed based on traditional method and indigenous knowledge of Ethiopian seed processors.

The study conducted in the Benishangul Gumuz region indicated that flowering of lowland bamboo happened progressively, from 2003 to 2020, following a wave of flowering from the northern part of the region to its southern part; flowering is now in its completion period. Similar to highland bamboo, seed collection and processing protocol for Ethiopian lowland bamboo are developed based on traditional methods and indigenous knowledge of Ethiopian seed processors.

Besides developing protocols for collecting and handling good quality bamboo seeds, a guideline is developed for the selection of superior clumps/culms that are used to obtain vegetative materials as well as seeds during bamboo flowering. Vegetative propagation techniques of the two indigenous and five well-performing introduced bamboo species are also provided.

Lastly, the author recommends that actors engaged in promoting bamboo plantations in Ethiopia make use of this technical manual.

1. Introduction

Ethiopia has one of the largest bamboo resources in Africa, with an estimated 1.47 million ha of two indigenous bamboo growing areas (INBAR, 2018a): *Oxytenanthera abyssinica* and *Oldeania alpina syn.Yushania alpina or Arundinaria alpina. Oxytenanthera abyssinica*, commonly known as "lowland bamboo", constitutes a great majority of the total national bamboo cover, estimated at about 85% (Kassahun, 2000). A recent remote-sensing-based inventory undertaken by INBAR (2018a) reported that the lowland bamboo cover of the country in the Benishangul Gumuz region (northwestern Ethiopia) alone was 944,756 ha, indicating that this species is greatly localized. However, highland bamboo is found distributed in the central, southern, and northern highlands of Ethiopia, constituting the remaining 15% of the cover (Kassahun, 2000; INBAR, 2018a). Studies by Semeneh *et al.* (2016) and INBAR (2010) indicated that natural bamboo (state owned) forests, especially in major lowland bamboo growing areas, are not under any form of management and have been shrinking rapidly because of lack of management after mass flowering and frequent forest fires.

After mass flowering of lowland bamboo in Metekel zone (2003) and subsequent years (2003–2020) in northwestern Ethiopia, seed collection and establishment of new lowland bamboo plantations from seedlings was started. Following seed availability, therefore, during the last about 17 years, government nurseries started seedling production and supporting individual farmers to establish plantations. Thus, unlike previous years in which lowland bamboo was found limited only as a natural forest, nowadays, it is being produced in plantations across the country. Highland bamboo is found both in natural and plantation forms in Ethiopia. Our field observation in August 2020 indicated cases where area coverage of highland bamboo plantations, derived from vegetative propagules, especially along most accessible sites such as along main asphalt roads (in northwestern Ethiopia), is increasing. One of the main challenges for promoting bamboo plantations is the lack of adequate planting material supplies of required species of desirable quality. From previous efforts, the propagating material used for establishing lowland bamboo is principally seed and to some extent wildlings; however, highland bamboo is principally propagated using a vegetative propagule, known as offset, of age one or two years.

During the last 12 years, more than 23 exotic bamboo species have been introduced from Asia and Latin America, seven of which were evaluated for their performance under multiplication trials of the Ethiopian Environment and Forest Research Institute, and five of which (*Dendrocalamus asper, Dendrocalamus hamiltonii, Dendrocalamus membranaceus,* *Bambusa balcooa, Bambusa vulgaris (*green) were found to be performing well in different agro climatic zones. As these species are found only in experimental and demonstration sites, the feasible means of propagating them is by vegetative reproduction/propagation, that is, by extracting planting material from experimental and demonstration sites and, whenever conditions allow, by importing additional seed from other areas in the origin.

Lack of bamboo planting material of required species in required quantity and using the best populations as planting material sources (quality) has always been a challenge due to the flowering nature of bamboo and the lack of standardized selection protocols and vegetative propagation methods. INBAR's previous and current development projects have set up many nurseries to scale up bamboo planting material production in Africa and Latin America. Moreover, INBAR is also undertaking ex-situ genetic conservation activities, including setting up bamboo arboretums and research plots. These activities are aimed at enabling large-scale bamboo-based landscape restoration activities.

This report is produced after assessing populations of bamboo forests, characterising their reproductive phenology and determining seed procurement aspects of bamboo species in Ethiopia. The objective of this study was to obtain a better understanding of conservation of bamboo genetic resources in theory and practice, specifically to understand the growth and performance of indigenous and introduced bamboo species, to validate the species for expansion, and to set recommendations for enabling conditions further.

2. Methodology of the study

Desk review: Published and unpublished literature from different international and national sources were reviewed for general information on growth characteristics, reproductive biology and utilisation of lowland, highland and introduced bamboo species.

This study was done in five major bamboo growing regions of Ethiopia: the Benishangul Gumuz, Amhara, Oromia, Southern Nation Nationalities and Sidama regions. At regional levels, widely growing zones of the two indigenous bamboo species (lowland bamboo and highland bamboo) were identified in consultation and discussion with regional experts. Consequently, woreda[2] level growing areas were identified with zonal experts, and so was identification of the kebeles[3] in major bamboo growing woredas. Lastly, from selected zones, major bamboo growing woredas were considered for data collection. The study on introduced bamboo species was conducted on research and demonstration sites distributed around the country. Field inventory was conducted from 10 September to 25 September 2020. The detailed methodology followed for indigenous and introduced species is described below.

Lowland bamboo

Field assessment was conducted in the Benishangul Gumuz region (Pawe woreda, Metekel zone), Amhara region (Jawi and Gangua woredas, Awi zone), Oromia region (Dabo woreda, Buno Bedele zone), and Sidama region (Wondo Genet woreda, Sidama zone). In each study woreda, three sample sites were selected based on the known lowland bamboo coverage and performance, where one representative sample plot of 20 m × 20 m (400 m^2) was established in each selected site. Growth parameters, such as culm DBH and culm height, were assessed by categorising bamboo culms into three age classes (<1 year, 1–3 years and >3 years). Clump size, that is, perimeter of the clump at 30–40 cm height from the ground, was measured using metre tape; number of culms per clump and number of clumps per plot were also counted in the field. Geographic information, that is, latitude, longitude, and altitude, were recorded using Garmin etrexGPS, and slope was measured using a clinometer.

Highland bamboo

A field reconnaissance survey was conducted in the Amhara region (Sinan woreda, East Gojjam zone; Banja woreda, Awi zone), SNNP region (Chencha woreda, Gamo Zone; Eza

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[2]Woreda, Amharic word, meaning administrative unit equivalent to "district"

[3]Kebele, Amharic word, meaning the next lower administrative unit after woreda, equivalent to Peasant Association in rural areas

and Gumer woreda, Guragie zone; Masha woreda, Sheka zone), and Oromia region (Dire Enchini woreda, West Shoa zone; Seka Chokorsa woreda, Jimma zone).

In each study woreda, three sample plots were considered for data collection. The plot size for the data collection was 400 m^2 (20 m × 20 m). In each plot, the number of culms was counted and DBH and height of the culms from three different age groups were measured. The internodal length of 30 sample bamboo culms was measured along the height, 1.3 to 3 m above ground.

Introduced bamboos

Selected sites for field inventory included the Amhara region (Chagni, Awi zone; Piccolo (Bikolo) Abay, West Gojjam zone; Bezawit, Bahir Dar Zuria), Oromia region (Jimma, Jimma zone; Debrezeit, East Shewa zone); SNNP region (Tepi, Sheka zone; Arbaminch and Chano nursery, Gamo zone; Wondo Genet, Sidama zone), and Benishangul Gumuz region (Abende Mingida, Assosa zone). At the time of establishment, the assessed research plots had 4 rows × 4 columns (16 seedlings) with three replications. The literature was consulted for Bako (West Shoa zone, Oromia region) and Kobo (North Wollo zone, Amhara region).

A total of eight species tested in seven different sites (Table 1) were considered in this study, and good performing species were determined. The eight introduced bamboo species considered in this assessment included *Bambusa vulgaris, Bambusa bambos, Bambusa balcooa, Dendrocalamus asper, Dendrocalaus hamiltonii, Dendrocalamus membranaceus, Dendrocalamus giganteus* and *Guadua amplexifolia* (Yigardu et al., 2016b).

Growth was determined by taking two clumps from each plot and considering three plots from each species and site. Growth parameters, such as culm DBH and culm height, were assessed by categorising bamboo culms into three age classes (<1 years, 1–3 years and >3 years). Clump size, that is, perimeter of the clump at 30–40 cm height from the ground, was measured using metre tape; number of culms per clump and number of clumps per plot were also counted in the field.

Geographic and ecological information, that is, latitude, longitude and altitude, were recorded using Garmin etrex GPS, and slope was measured using a clinometer. Climate information (rainfall and temperature) was consulted from published literature (meteorological data) and other secondary sources. However, due to the unexpectedly low or high climate information obtained from woreda unpublished reports, the ENACTS (Enhancing National Climate Services) Grid Data is used for each site.

Reproductive biology of indigenous bamboos

Following discussion on the current flowering of bamboo forests in Benishangul Gumuz region, northwestern Ethiopia, a field visit was made to Buldigilu Gambisheri kebele of Assosa woreda, where one of the two remaining flowering bamboo forests (Buldigilu Gambisheri kebele and Mao-Komo woreda) is located. Discussion was held with a lowland bamboo seed supplier in the kebele who collected and distributed lowland bamboo seed to the region and many other areas in Ethiopia. The nature of flowering, time for flowering-fruiting-seed maturity, and seed collection methods were discussed, and photographs were captured. Similarly, Adiyo woreda of Keffa zone (SNNP), southwestern Ethiopia, was visited to document the nature of flowering, time for flowering-fruiting-seed maturity, and seed collection methods of highland bamboo. Highland bamboo seeds were collected from Adiyo woreda, and (representative) lowland seeds were obtained from the lowland bamboo seed supplier for characterisation and quality testing.

Seed processing, characterisation and quality testing

Seed processing, characterisation and quality testing was conducted at the processing site and seed laboratory of the Central Ethiopia Environment and Forest Research Centre (CEE-FRC) in Addis Ababa. Seed characterisation and quality testing was conducted following ISTA seed testing standard methods adopted by the CEE-FRC tree seed laboratory. The seed processing method and procedure were determined in collaboration with senior seed processors at CEE-FRC.

3. Growth and performance of bamboos in different agro-climatic zones of Ethiopia

3.1 Bamboo species

3.1.1. Lowland bamboo (Oxytenanthera abyssinica)

3.1.1.1. Distribution of lowland bamboo populations in Ethiopia

Lowland bamboo grows from 500–1800 masl with a mean annual temperature between 20 and 35°C and a mean annual rainfall of 1150 mm but also tolerating erratic mean annual rainfall as low as 600 mm (PROTA, 2016). In Ethiopia, lowland bamboo is found in Kolla/lowland agro climatic zones, which are mostly confined to the western side of the country. The major portion of lowland bamboo forestd is 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). It grows in five regions in Ethiopia: the Benishangul Gumuz, Oromia, Amhara, Gambela and Tigray regions (Yigardu et al., 2019).

In Africa, lowland bamboo is found distributed throughout tropical Africa, outside the humid forest zone, in more than 30 countries, including Angola, Benin, Burkina, Burundi, Cameroon, Central African Repu, Chad, Congo, Equatorial Guinea, Eritrea, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bissau, Gulf of Guinea Is., Ivory Coast, Kenya, Malawi, Mali, Mozambique, Niger, Nigeria, Northern Provinces, Senegal, Sierra Leone, Sudan, Tanzania, Togo, Uganda, Zambia, Zaïre, and Zimbabwe (Kew Science (2021, 2021; PROTA, 2021)

O. abyssinica grows on very poor soils and various types of parent rock, but much of its distributional range is the old crystalline basement complex. Soil fertility is not a major influencing factor. The species is associated with impoverished acrisols and ferralsols, moderately fertile luvisols, and younger relatively nutrient-rich cambisols and nitisols. It is essentially absent from arenosols that have poor moisture retention and gleysols with poor drainage (PROTA, 1998). Key site factors are good drainage combined with access to reliable rainfall. 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 that are also favourable for its growth. Saline conditions are unfavourable.

The lowland bamboo in Ethiopia is mainly found in the Combretum-Terminalia deciduous woodlands of Benishangul Gumuz region, followed by the Amhara region, part of the western

Oromia region and Gambella region. Domesticating the species has also been underway in the aforementioned regions and in Tigray and SNNP regions.

According to Yigardu et al. (2016), many woreda found in different zones of different regions are identified for their lowland bamboo potential (Figure 1):

(1) Benishangul Gumuz region: Assosa zone (Bambassi, Assosa, and Homosha woredas); Metekel zone (Mankush, Mandura, Guba, Pawe, and Dibate woredas); Kemashi zone (Kemashi woreda); and Mao-Komo especial woreda

(2) Oromia region: EasetWolega zone (Sasiga, Diga, NunuGumba, WamaAgalo, Gida Ayana, Leka Dullecha woredas); West Wollega zone (Gimbi, Kondala and Begi woredas); and BunoBedele Zone (Dabo Hanna and Didessa woredas)

(3) Amhara region: Awi zone (Jawi, Guangua, Ankesha and Zigem woreda); East Gojjam zone (Debre Elias and Baso-Liben woreda); West Gojjam zone (Bure, Wombera, and Dembecha woreda); and North Gondar zone (Metema, Quara, Alefa, Tach Armach'ho, Tsegede and Adiarkay woredas)

(4) Tigray region: Mierabawi Tigray zone (Welkait, Tsegede and KaftaHumera);

(5) Gambella region: Agnuak zone (Abobo, Gog, Dima and Gambela woredas) and Majang zone (Godere and Megshi woredas)

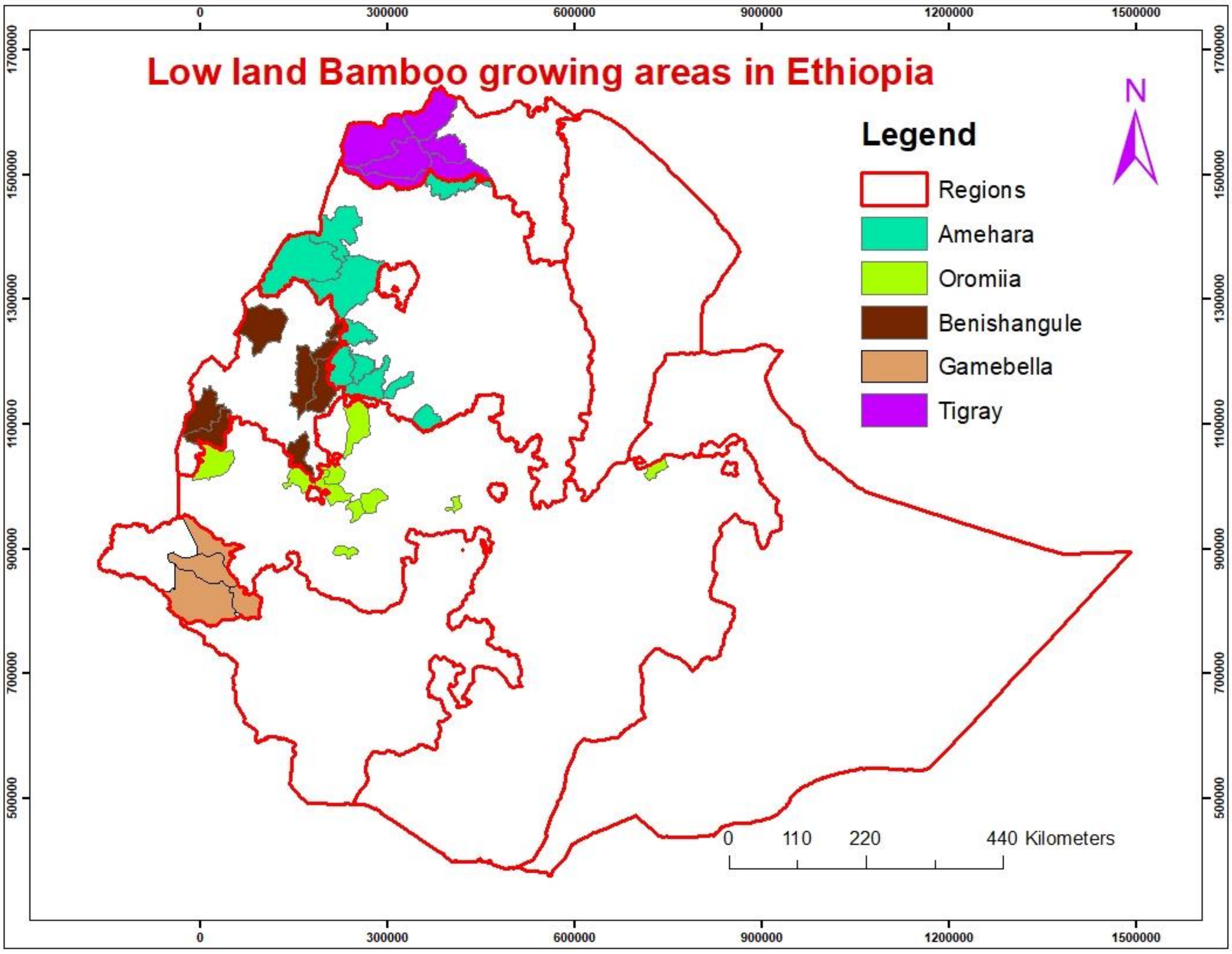


Figure 1: Lowland bamboo growing woredas in five administrative regions (Amhara, Oromia, Benishangul Gumuz, Gambela and Tigray) of Ethiopia.

The woredas from different regions are indicated by different colours.

3.1.1.2. Growth characteristics of lowland bamboo

Growth characteristics of lowland bamboo documented by Yigardu et al. (2016) are as follows: Initial growth of lowland bamboo stands developed from 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 and with many thinner 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 huge biomass in a short period of time.

The maximum height of culms at the age of two in the Sherkole area of Homosha woreda was recorded to be more than 5 m, and the number of culms per clump was more than 12. At the Jimma observation site, planted seedlings of lowland bamboo produced 15 culms/clump with an average height of 4 m and diameter of 3.5 cm at the age of two years. Both plant and clump size dramatically increase in the third rainy season. Surprisingly, at the age of three years, a clump produced an average of more than 36 culms with a maximum height of 8 m and diameter of 4.5 cm. Culms reach full height and diameter within 4–8 years. Often, in bamboos, stands established using offsets reach harvesting in a shorter time than those from seedling origin. Thus, under good management, stands established using offset methods are expected to start production from the fourth year.

3.1.1.3. Distribution of populations and growth characteristics of lowland bamboo in natural and plantations (result of the current study)

Distribution of lowland bamboo populations

The field assessment was conducted in Benishangul Gumuz regional state (Pawe woreda of Metekel zone), Amhara regional state (Jawi and Gangua woreda of Awi zone), Oromia regional State (Dabo woreda of BunoBedele Zone), and Southern Nation and Nationalities (Wondo Genet, Sidama Zone).

The altitude of the growing sites in this study ranged from 1110–1765 masl (Table 1). The lowest elevation (1100 masl) was recorded at the Mender-7 and Mender-10 Kebele sites. Two of the highest elevation sites were the Abi Teklu private forest plantation (1700 masl) and the Wondo Genet site (1765 masl). The Abi Teklu private forest plantation site is a plantation established from seedlings four years back. This site receives nearly average rainfall (1432.7 mm annually) and temperature (average minimum of 11°C and average maximum of 28.4°C) of all the sites. Wondo Genet is the site that receives the lowest annual rainfall (1049.6 mm) and has the lower annual temperature (average minimum of 10.7°C and average maximum of 25.3°C) among the studied sites. The slopes of the study sites range from 5% to 60% (Table 1).

Table 1: Ecological and climatic characteristics of the studied areas for lowland bamboo in different regions of Ethiopia

S.No.	Region	Zone	Woreda	Plot	Latitude	Longitude	Altitude (ma.l)	Av. An. rainfall (mm)	Av. Min. Temp. (°C)	Av. Max. Temp. (°C)	Slope (%)
1	BG	Metekel	Pawe	Mender-7 (On-station, PARC)	11°18.925' N	036°25.09'E	1110	1596.3	14.2	31.9	5
2	BG	Metekel	Pawe	Mender-10	11° 19.364'N	036°27.939'E	1100				10-15
3	BG	Metekel	Pawe	Mender-12 (Debrework Mich.)	11°19.714'N	036°30.184'E	1143				5-10
4	BG	Assosa	Bambasi	Ambesachaka	9°54.453'N	034°39.478'E	1491	1391.38	10.0	29.3	5-10
5	BG	Assosa	Homosha	Sherkole camp	_	-	_	1127.22	10.9	29.4	5-10
6	Amhara	Awi	Jawi	Embasir (SimidaFrint Kebele)	11°25.258'N	036°35.192'E	1276	1633.79	14.2	31.4	45-60
7	Amhara	Awi	Jawi	Addis AlemGebriel	11°24.413'N	036°36.212'E	1227				20-25
8	Amhara	Awi	Jawi	Guder-Kava	11°37.274'N	036°37.837'E	1237				20-25
9	Amhara	Awi	Guangua	Abi Teklu private forest land	10°56.683'N	036°30.544'E	1700	1432.69	11.0	28.4	45
10	SNNP		Wondo Genet	Wondogenet Agri. Res. Center (compass)	07°05.506'N	038°37.172'E	1765	1049.59	10.7	25.3	5
11	Oromiya	Buno Bedele	Dabo	Dabo (farmer)	07°11.795'N	035°25.296'E	1370	1716.92	10.4	26.8	5
12	Oromiya	Buno Bedele	Dabo	Dabo (church)	08°39.836'N	036°23.628'E	1423				5
13	Oromiya	Buno Bedele	Dabo	Dabo (community)	08° 39.761'N	036°23.754'E	1434				5

3.1.1.4. Growth of lowland bamboo across varying climatic conditions in the studied natural and plantation forests

Growth parameters considered in this study were only directly measurable values, such as DBH and height and parameters, which can be directly counted, including number of culms per clump and number of clumps per hectare. Biomass was not determined, as it required more resources.

The average DBH of lowland bamboo of 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 the Wondo Genet) (Table 2). The Mender-7 site, which is specifically located within the compound of Pawe Agricultural Research Center in Metekel zone, had culms of bigger average height (11 m) and moderate number (30) of culms per clump. This plantation was established 13 years ago by the then Forest Directorate of the Ethiopian Institute of Agricultural Research Institute (EIAR).

The three highest numbers of culms (59, 57 and 56) per clump were counted at Guder-Kava, Mender-12 (Debrework Michael) and Abi Teklu private forest sites, respectively, whereas the lowest (14) was counted at the Mender-10 site. Despite the high density of culms per clump, the Guder-Kava site (of low altitude, 1273 masl) had one of the lowest in DBH and height that might be related to problems in managing the clumps and partly on soil conditions; this will be further explained after discussing the analysis of collected soil samples. Besides the high number of culms per clump, Debrework Michael church and Abdi Teklu private forest sites had remarkably attractive numbers of clumps per plot utilising the area effectively.

The relatively good performance of lowland bamboo at Wondo Genet and Abdi Teklu private plantation forest sites, which are of respective higher altitudes of 1765 and 1700 masl as compared to the other studied site, indicates that lowland bamboo performs well even at higher elevations. From the graph (Figure 2A), it can be deduced that lowland bamboo can perform well in higher elevations more than what is often stated as a higher margin, 700/1800 masl in different publications (Philips, 1993; Yigardu et al., 2016; Ensermu et al., 2000). It can produce even higher culm DBH values than 5.57 cm (recorded DBH at Wondo Genet) at higher elevations that may extend to 2000 masl.

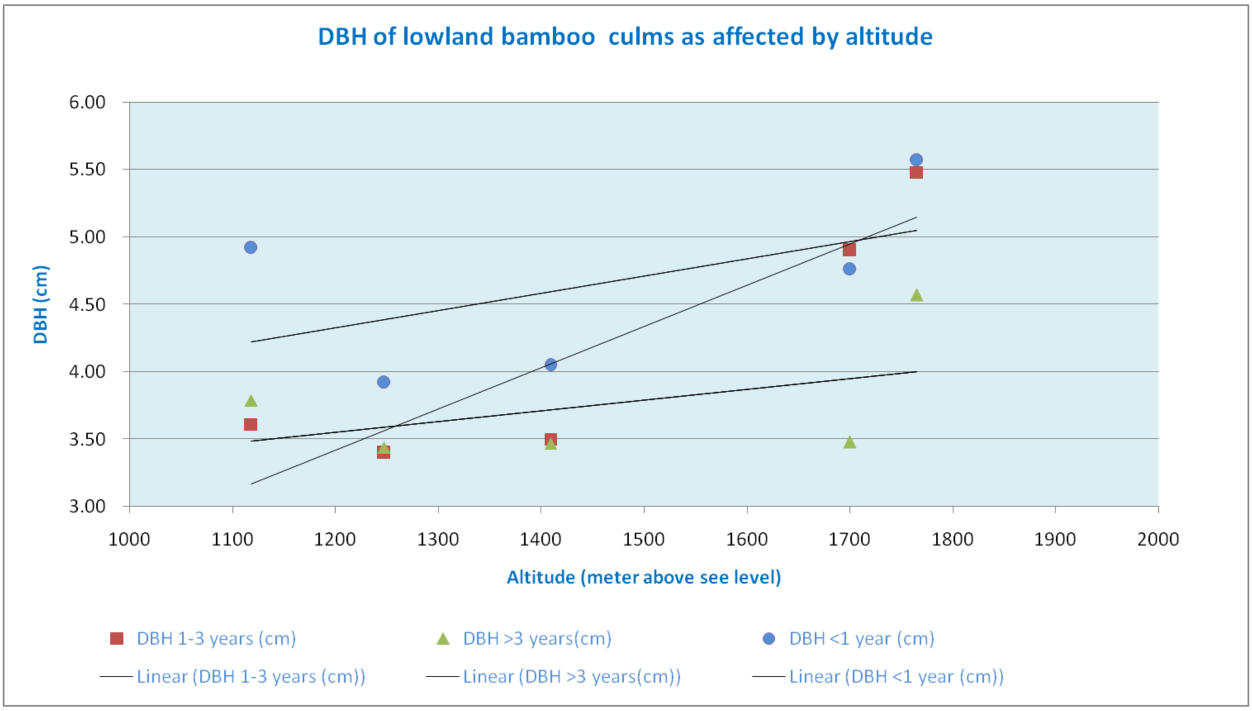
From the graph (Figure 3 A and B), the trend of DBH growth against temperature of the studied sites, it can be deduced that growth of lowland bamboo was higher in areas that received lower average annual minimum (10.7°C) and maximum temperatures (25.3°C) such as

Wondo Genet. Thus, promoting lowland bamboo in lower minimum temperature areas (as low as 10.0 oC) is recommended.

The average DBH of culms for the 13 sites was 4.4 cm, 3.7 cm and 3.6 cm for culms of ages <1, 1–3 and > 3 years, respectively. Bamboo produces new shoots that are thinner in the first shooting seasons after it is newly established from seed or vegetative means, but afterwards, as the rhizome grows bigger, emerging shoots become bigger and eventually the plant reaches its maximum size. Considering the age of the selected stands that were regenerated or planted at least 10 years ago, it is an adequate time for lowland bamboo to attain maturity.

However, unsustainable management of the forests is observed to result in lower growth performance and yield. The bamboo forest in Mender-10 (Pawe woreda) that is owned by a community group is a good case to indicate management problems. The forest is a regenerated forest after the mass flowering event in the area. The stand was subjected to interference by the non-group members in the form of unsustainable harvesting practices (clear cutting and no selective cutting). The level of disturbance was high. We randomly enumerated three clumps from each of the three sample plots and observed that 15% of the culms of the clumps in the plots were affected by clear cutting of all ages at all clump positions, 50% of the culms were cut at higher positions, and only 11% of the standing culms were economically important. The forest had an average culm DBH of 4.7 cm, whereas the number of culms per clump was one of the lowest (14).

The size regularity degree of bamboo stands is a measure of stand quality. Well-managed bamboo stands have uniform DBH and height. Under the conditions of the selected sites, DBH of <1-year bamboo culms were higher than DBH of 1–3 years and >3 year culms, indicating that the stands were not managed stands and have been subjected to unsustainable harvesting, which included cutting of young ones. This observation is in line with the report by INBAR (2018b), which indicates that (communal) bamboo forests in Ethiopia are over-harvested and/or unsustainably managed, with a higher number of old poles (3+ years) standing in the bamboo clump.



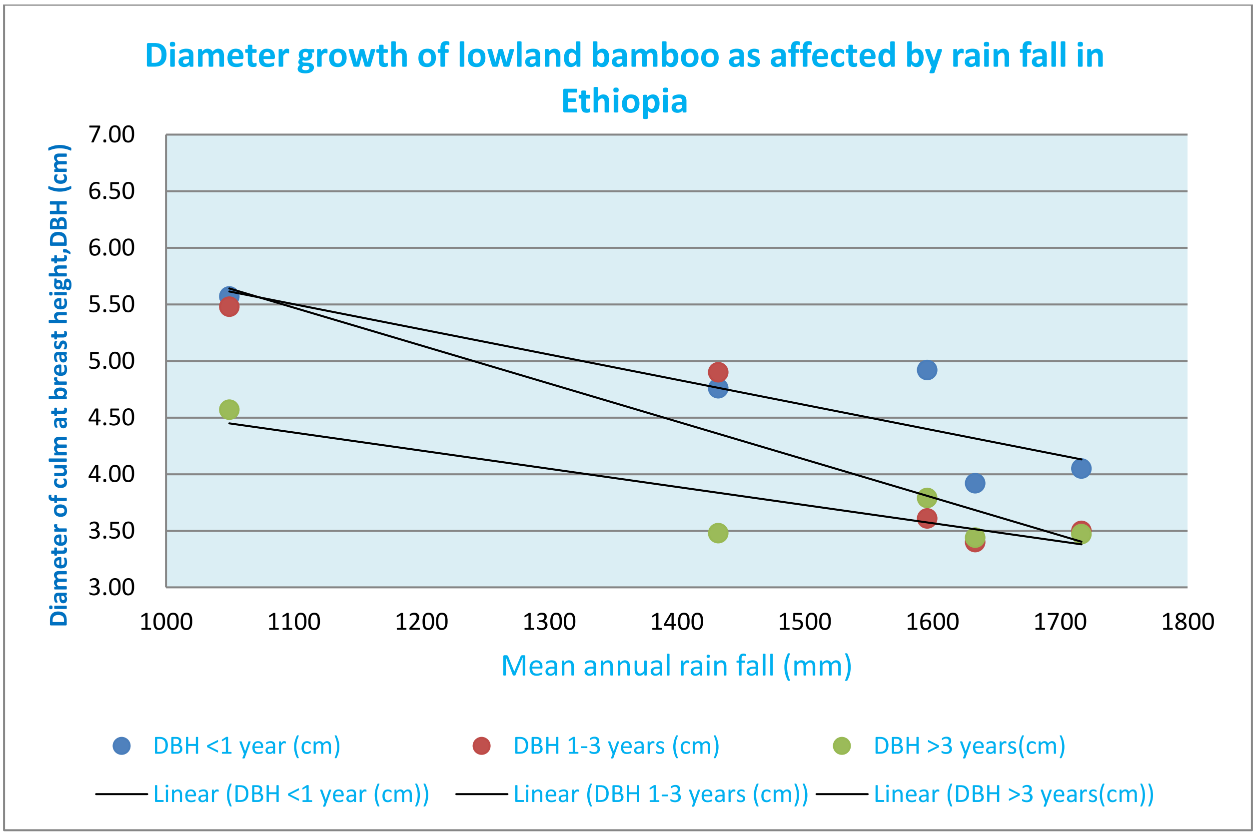


Figure 2: Average DBH of lowland bamboo culms per age group along altitudinal (A) and rainfall (B) gradient.

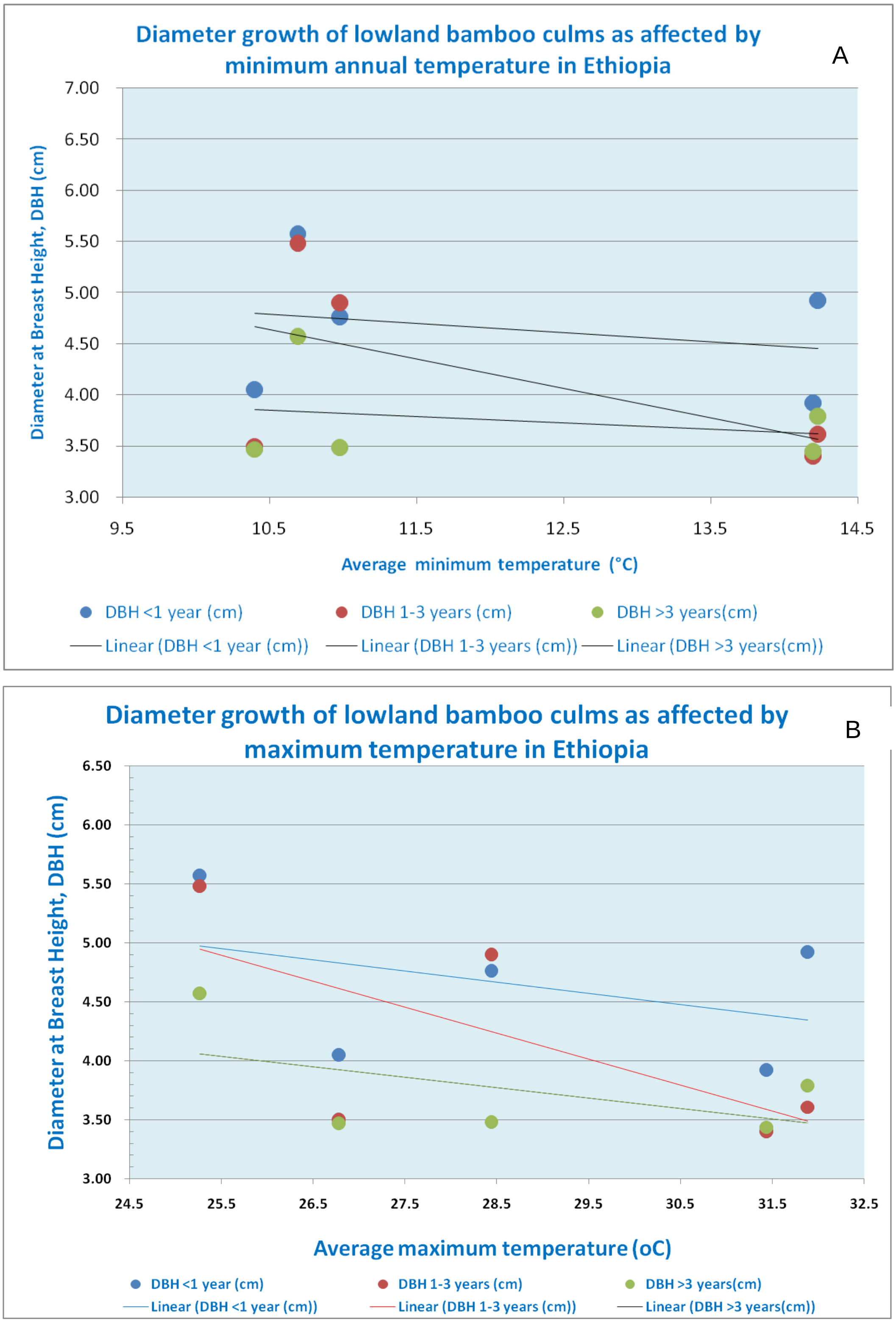


Figure 3: Average DBH of lowland bamboo culms per age group along minimum (A) and maximum (B) temperature gradient

Table 2: Growth characteristics of lowland bamboo in selected sites across regions of Ethiopia

S. No	Woreda	Plot/ Kebele	Origin of bamboo plot (natural or planted)	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	Mender-7 (On-station, PARC)	Planted	5.3	3.74	3.91	11	9	13	30	13	None	Research organization
2	Pawe	Mender-10	Natural (regenerated)	4.69	3.42	3.95	11	9	13	14	19	None	Farmer
3	Pawe	Mender-12 (Debrework Michael)	Natural (regenerated)	4.78	3.66	3.5	11	9	13	57	77	None	Ethiopia orthodox Tewahido church
4	Jawi	Embasir (Simida Frint Kebele)	Natural (regenerated)	3.92	3.4	3.44	8	10.5	13	29	19	Once a time of farmland preparation	Community
5	Jawi	Addis AlemGebriel	Natural (regenerated)	3.90	2.66	3.32	8	10.5	13	26	36		Individual farmer
6	Jawi	Guder-Kava	Natural (regenerated)	3.39	3.36	3.3	8	10.5	13	59	22		Individual farmer
7	Guangua	Abi Teklu private forest land	Planted	4.76	4.9	3.48	12	12	12	56	8	None	Individual farmer
8	Wondo Genet	Wondogenet	Planted	5.57	5.48	4.57	11.33	10.5	12	25	-	None	Research organization
9	Buno Bedele	Dabo	Natural (matured forest)	4.24	3.945	3.62	6.125	6	6.5	-	35	Once	Individual farmer
10	Buno Bedele	Dabo	Natural (matured forest)	4.01	3.25	3.26	5.5	5	6	-	8	Once	Protestant church
11	Buno Bedele	Dabo (Community)	Natural (matured forest)	3.89	3.3	3.54	6	5.5	6.5	-	6	Once	Community

3.1.2. Growth and performance of highland bamboo

3.1.2.1. Distribution of highland bamboo populations in Ethiopia

In Ethiopia, highland bamboo is distributed at altitudes ranging from 2200 to 4000 masl (Philips, 1995, Kelbessa et al., 2000) in montane forest, often on volcanic soils and forms extensive pure stands, occurring in the *Afrocarpus falcatus (Podocarpus falcatus*) rainforest and with *Juniperus procera* in drier forests. It is found in different parts of Ethiopia as forest stands and plantations. Highland bamboo growing areas are indicated in Table 3 and Figure 4 below, as summarized by different reports (INBAR, 2018b; Yigardu et al., 2016).

Table 3: Highland bamboo growing areas in Ethiopia

Region	Zone	woreda/Woreda
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, DegaDamot
	North Shoa	Tarmaber
	South Wollo	Debre-Sina
Oromiya	West Arsi	Koffale and Arsi-Negele, Kokosa
	Bale	Goba
	West Shoa	Dire Inchini and Shenen
	Jimma	Dedo, Seka-Chekorsa, Mana, Kersa, Agaro, Gera, Gera-Lola
Sidama		Hula, Arbegona, Bensa
Southern Nations, Nationalities and Peoples region	Gedeo	Bule, YirgaChefe, Kochore
	Gamo	Chencha, Arbaminchzuria, Bonke, Kamba, Boreda, Kucha, Mirab Abaya, Deramalo, Dita,
	Gofa	Geze-Gofa
	Guraghe	EZA, Gummer, Cheha, Geta, Enemore, Endegagn, Sodo, MuhirnaAklil, Gedabanogutazerwelene,
	Hadya	Misha, Anlemo, Duna
	Kembata	Angecha, DoyoGena
	South Omo	North Ari
	Kefa	Gawata, Decha, Adiyo, Gesha); Dawro zone (Tercha, Esera), SegenHizboch (Amaro)
	Wolayta	SodoZuria
	Sheka	Masha, Anderacha, Debub Bech; MizanTeferi-Kulish, Wushwush-Bonga, Bonga-Ameya

The field assessment was conducted in Amhara regional state (Sinan woreda, East Gojjam zone; Banja woreda, Awi zone), SNNP regional state (Chencha woreda, Gamo zone; Eza and Gumer woreda, Guragie zone; Masha woreda, Sheka zone), Oromia regional state (Dire Enchini woreda, West Shoa zone; Seka Chokorsa woreda, Jimma zone).

The altitudinal range of the study sites lies between 2387 masl and 2979 masl. The annual rainfall is between 1123.82 mm and 2458.32 mm (Table 4).

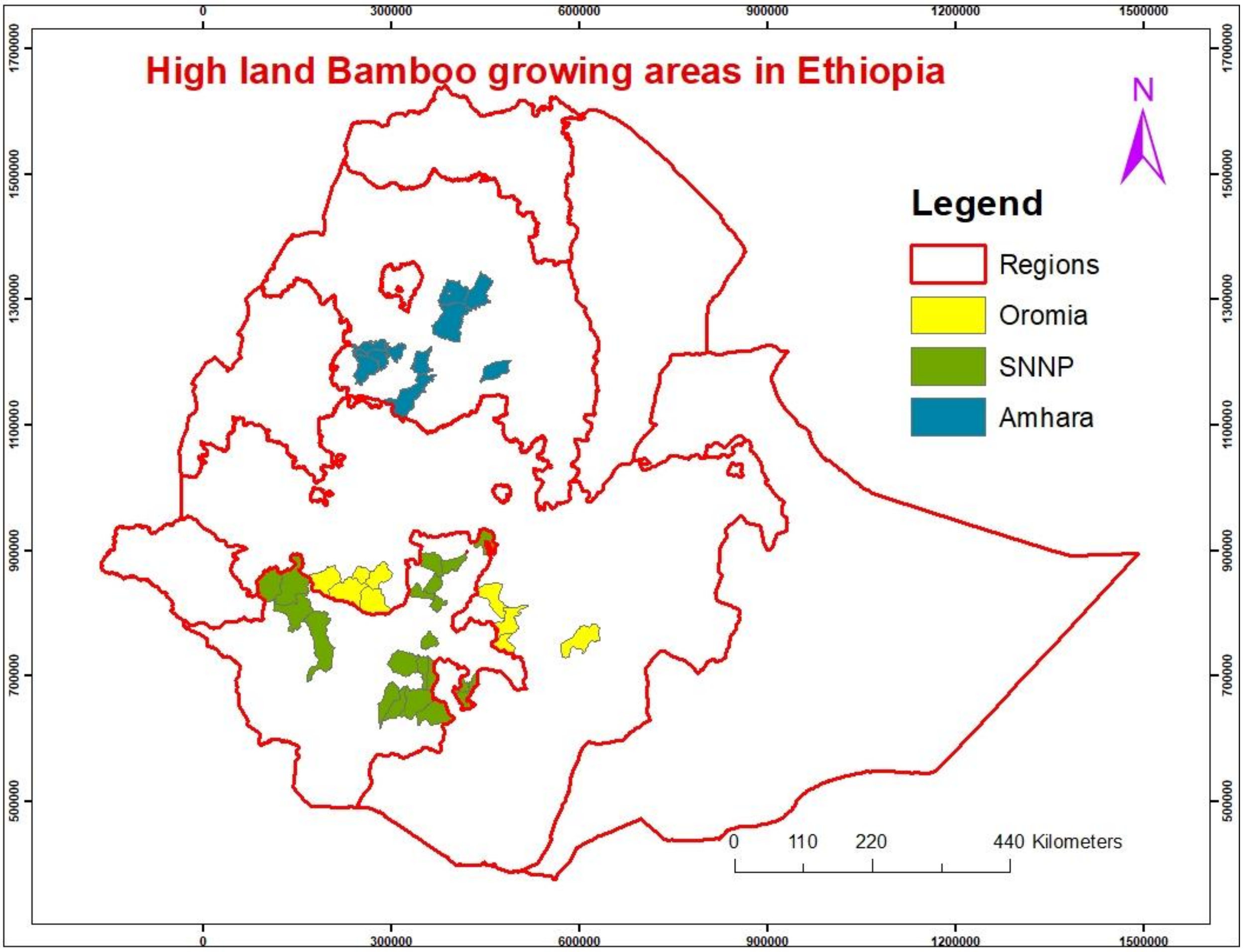


Figure 4: Highland bamboo growing woredas in three regions of Ethiopia; The woredas from different regions are indicated by different colours.

Table 4: Site characteristics of the studied areas for highland bamboo

S. No	Region	Zone	Woreda	Plot	Longitude	Latitude	Altitude (masl)	Slope (%)	Rainfall (mm)	Av. Min. Temp. (°C)	Av. Max. Temp. (°C)
1	SNNP	Gamo	Chencha	1	037° 34' 02.4"	06° 12' 44.3'	2571	0–2	1123.82	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	SNNP	Gurage	Eza and Gumer	1	038° 07' 00.7"	08° 06' 26.5"	2925	5–8	1167.49	9.1	24.0
				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	Oromia	West Shoa	Dire Enchini	1	037° 38 '17.8 "	08° 50' 40.4 "	2454	2–5	2458.32	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	Sidama	Sidama	Hula	1	038° 33' 18.4"	06° 28' 50.6"	2744	2–5	1357.8	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	Amhara	East Gojjam	Sinan	1	036°4' 9.06"	11°67' 8.56"	2879	> 45	1372.1	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	SNNP	Masha	Masha	1	035° 30. '09.9"	07° 37' 09.2"	2423	0–2	2144.61	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	Amhara	Awi	Banja	1	036° 57' 50.6"	10° 54' 79.0"	2500	2–5	2142.97	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	Oromia	Jimma	Seka Chokorsa	1	036° 35' 66.9"	07° 42' 92.7"	2387	0–2	1633.96	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: Climate information of each specific site is obtained by analysing the ENACTS (Enhancing National Climate Services) *Grid Data.*

3.1.2.2. Stand structure of highland bamboo in the present study areas

Bamboo stand structure indicates the growth and productivity of bamboo plantations/forests. Stand structure is the vertical and horizontal organization component of the bamboo culm (culms and rhizomes) in ages and numbers, which determines its properties and functions. Higher productivity of highland bamboo forest can be achieved by having proper density, age structure, size uniformity of culms and rhizomes. Culm age structure of the studied sites is indicated in Table 5 below.

Table 5: Average number of culms by age class in different locations per hectare

Age	Chencha	Eza and Gumer)	Dire-Enchini	Hula	Sinan	Masha	Banja	Seka Chokorsa
< 1 year	1432.5	1692	1550	1450	1706	1733.3	3025	1991.66
1-3 years	4932.5	3608	2800	5457.5	4256	3225	6508	4883.33
> 3 years	4200	2508	900	900	5493	1466.6	2033	2116.66
Total culms/ha	10565	7808	5250	7808	11456	6425	11566	8992

It was observed that productivity varied with the application of silvicultural practices; thus, state-owned and community-owned bamboo forests lacked proper silvicultural practices, including harvesting of mature culms, whereas while farmers/private bamboo forests were relatively under good management. Rampant harvesting of young bamboo culms was a common practice in state-owned and community-owned bamboo forests. State-owned bamboo forests were the most unmanaged forests, as compared to community, institution/church and private bamboo forests in Ethiopia (INBAR, 2018b).

The data from the study sites showed variability in total culm number per ha among sites. The highest culm number was counted in Banja woreda (11566 culms/ha) and the lowest culm number was in Dire Enchini (5250 culms/ha). This is attributed mainly to market-oriented harvesting of selected quality bamboo culms based on the interest of the buyers.

Common to many growing areas was dead rhizome and stumps, which were not extracted out in most *O. alpina* growing areas. This again favours underground congestion and affects the running of young rhizomes as well as culm emergence. In general, it has been noticed that there were too many poor and deformed mature bamboo culms in *O. alpina* stands of the study areas with fewer numbers of young culms.

The age structure of highland bamboo (Figure 5) reflects the sustainability of the current management practices (especially harvesting) and growth environment. The ideal age structure is 25%:25%:25%:25% between 1, 2, 3 and 4 or more years. From Figure 5, highland bamboo forest in Banja, Masha, and Dire-Enchini were in good conditions, whereas Sinan, Chencha site will face potential risk of regeneration of young stands. Analysis of the management practices and climate-soil conditions will be important for expansion and sustainable management of highland bamboo.

Bamboo is a woody grass that produces new bamboo shoots or bamboo poles every year, and old bamboo poles in a clump die out every year. Sustainable harvesting (harvesting of 3+ years) improves the quality of bamboo forests as well as bamboo poles (INBAR, 2018b).

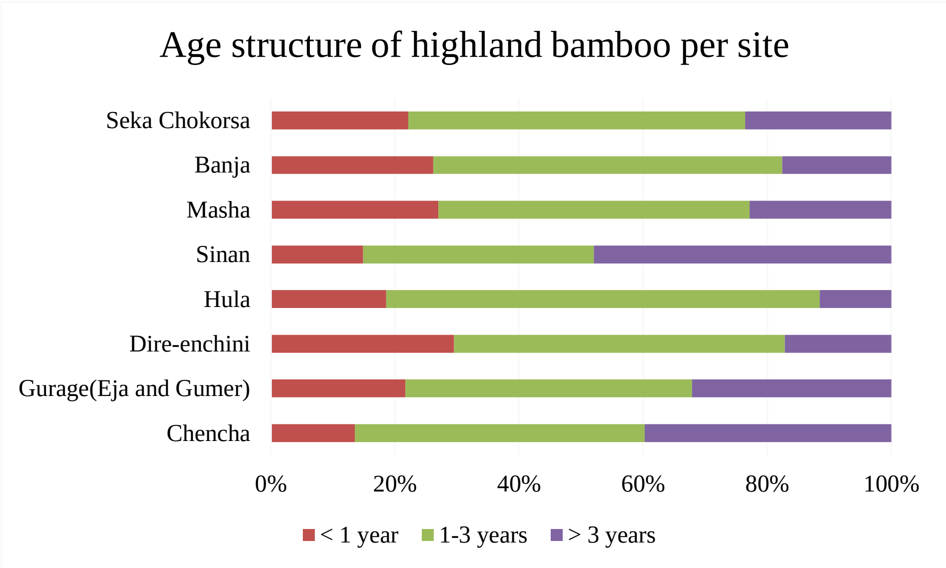


Figure 5: Age structure of selected highland bamboo stands selected from across the country in Ethiopia

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

The average DBH of highland bamboo for Chencha Zuria and Sinan woreda was between 4.7 cm and 8.2 cm, respectively. The average height of the highland bamboo culm varied between 10.3 and 15.0 m (Table 6). The internodal length of the elongating culm increases gradually from base towards the middle portion of the culm and decreases upwards. The average internodal length of highland bamboo along the height 1.3 to 3 m ranged from 33.2 cm in Hula to 71 cm in Sinana. The results indicated higher values of growth parameters in Sinana woreda (assessed at about a 40–60% slope in the ravine area) as compared to other sites.

3.1.2.3. Growth of highland bamboo across varying climatic conditions in the studied forests

Despite management and landform variations of the studied sites, DBH of highland bamboo showed an increase in DBH as altitude increased from 2387 masl (average altitude of the sample plots) at Seka Chekorsa to 2979 masl (average altitude of the sample plots) at Sinan. Variation in annual rainfall of the sites that ranges from 1123.8 mm (at Chencha) to 2458.00 mm (at Dire Enchini) had only slight effect on the growth performance of highland bamboo in the studied sites (Figure 6A and B). As the annual temperature (average minimum) increased from 5.3°CT at Hula to 9.1°C at Eza and Gummar, DBH growth showed a slightly increasing trend. (Figure 7A and B). he literature indicates that Ethiopian highland bamboo is found at altitudes ranging from 2200 to 4000 masl (Philips, 1995; Kelbessa et al., 2000; INBAR, 2018b; Yigardu et al., 2016).

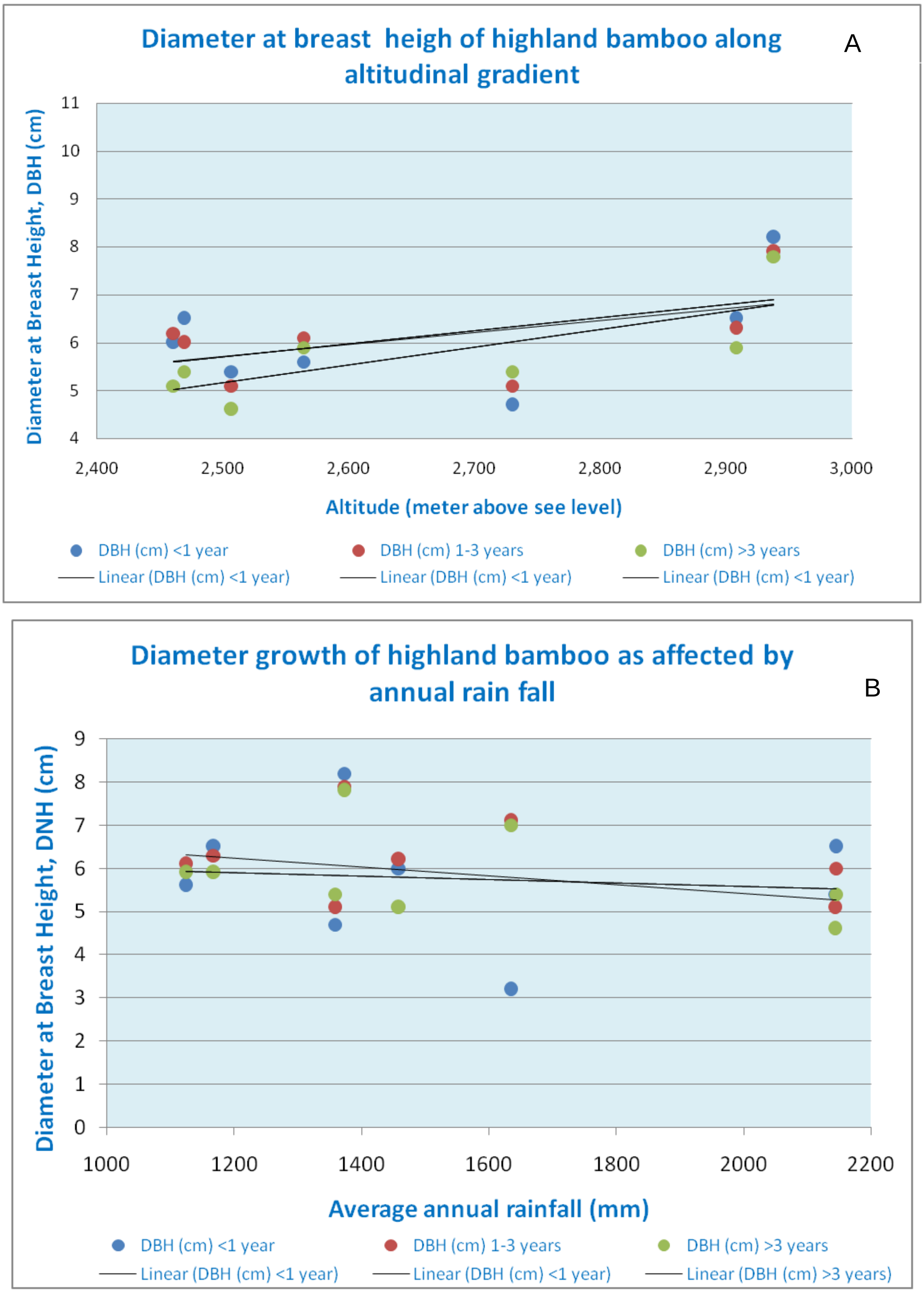


Figure 6: DBH of bamboo culms per age group along altitudinal (A) and rainfall (B) gradients

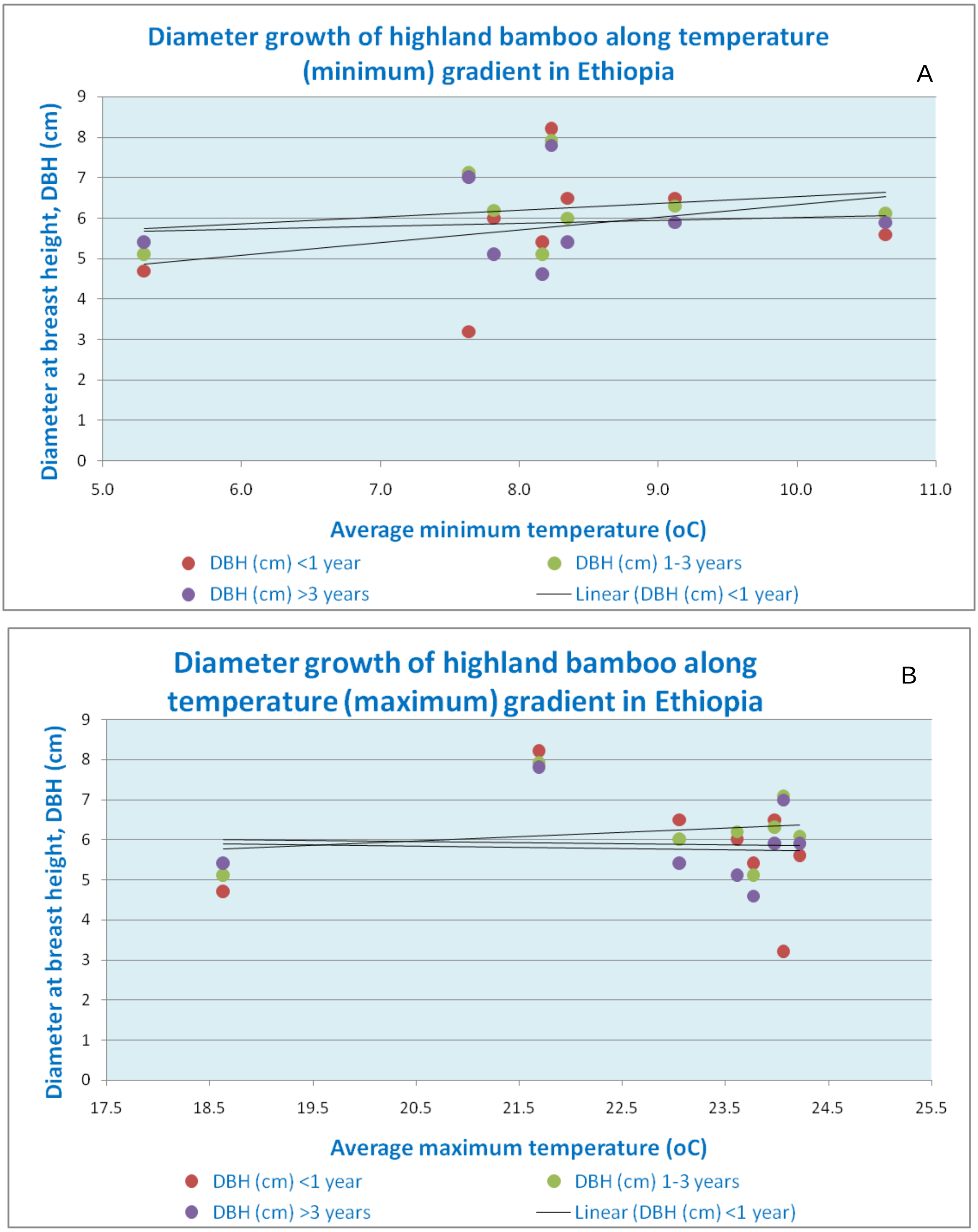


Figure 7: DBH of highland bamboo culms per age group along temperature gradient; Average maximum (A) and Average minimum (B) temperature gradients

Table 6: Growth of highland bamboo across varying climatic and soil conditions in the studied natural and plantation forests

No	Woreda	Altitude (masl)	Average annual rain fall (mm)	Average Min. temperature (OC)	Average. Max. temperature (OC)	DBH (cm) <1 year	DBH (cm) 1-3 years	DBH (cm) >3 years	Height (m) <1 years	Height (m) 1-3 years	Height (m) >3 years
1	Chencha	2,564	1123.82	10.6	24.6	5.6	6.1	5.9	10.7	11.5	11,4
2	Eza and Gumer	2,908	1167.49	9.1	24	6.5	6.3	5.9	12	12.1	10.7
3	Dire Enchini	2,461	2458.32	7.8	23.6	6	6.2	5.1	13.4	13.6	11
4	Hula	2,730	1357.8	5.3	18.6	4.7	5.1	5.4	8.1	10.3	10,3
5	Sinan	2,938	1372.1	8.2	21.7	8.2	7.9	7.8	14.6	15	15
6	Masha	2,469	2144.61	8.4	23.1	6.5	6	5.4	10.9	11.3	11
7	Banja	2,507	2142.97	8.2	23.8	5.4	5.1	4.6	7.2	7.2	7.2
8	Seka Chokorsa	2,503	1633.96	7.6	24.1	7.3	7.1	7	12.5	11.5	12.6

Note:

- *< 1 refers bamboo culms less than one year*
- *1–3 refers bamboo culms between one to three years*
- *> 3 refers bamboo culms older than three years*
- *Climate information of each specific site is obtained by analysing the* ENACTS (Enhancing National Climate Services) *Grid Data.*

3.2 Growth characteristics of introduced and adapted bamboo species in Ethiopia

3.2.1. Ecological conditions of introduced bamboos in Ethiopia

In the present study, the altitude of the adaptation and demonstration sites ranged from 1188 masl to 1920 masl (Table 7). The lowest elevations (1188, 1197 and 1200 masl) were recorded for the Chano Mile Nursery, Arbaminch University Nursery, and Tepi sites. Jimma and Chagni had relatively higher altitudes as compared to the aforementioned three sites but still with similar precipitation. The Chano Mile Nursery and Arbaminch University Nursery sites had the highest maximum temperature (36ºC each), followed by Tepi (30ºC) and Chagni (28.6ºC). The highest altitude recorded was 1920 masl at the Wondo Genet site, which, on the other hand, had the second lowest precipitation (1372 mm). Of all the assessed sites, DebreZeit received the least annual rainfall (980 mm).

Table 7: Geographic and agro-ecological information and climatic conditions of the testing sites for introduced bamboo species

S. No.	Name of testing site	Administrative location of the testing site			Lat-Long	Alt. (m)	Climate, average values			Year of establishment
		woreda	Zone	Region			Ann. RF (mm)	Max. Temp. (°C)	Min. Temp. (°C)	
1	Abende Mingida	Assosa	Assosa	Benishangul Gumuz	9°58'.0"N, 034°30'.10" E	1500	1350-1400	35	21	2009
2	Chagni	Guangua	Awi	Amhara		1700	1725	28.6	13.2	2010
3	Jimma	Mana	Jimma	Oromiya	7°46' N, 36°00' E	1753	1530	26.2	11.3	2010
4	Debre Zeit (Bishoftu)	Ada	East Shoa	Oromiya	08°44' N, 38°58' E	1855	980	28.3	8.9	2010
5	Wondo Genet	Wendo Genet	Sidama	SNNPR	7°19' N, 38°38' E	1920	1372	26.2	11.5	2009
6	Tepi	Yeki	Sheka	SNNPR	7°3' N, 35°18' E	1200	1678	30	15	2012
7	Arbaminch University	Arbaminch Town	Gamo	SNNPR	037°34' N, 06°04' E	1197	1725	36	23	2008
8	Kobo	Kobo	North Wollo	Amhara	12.08°N, 28° E	1470	630	33	20	2013
9	Bako	Bako	West Shoa	Oromiya	9°07' N, 37°05' E	1650	1237	27	13	2010
10	Chanomille Nursery	ArbaminchZuria	Gamo	SNNPR	037°36' N 06°07' E	1188	1725	36	23	2004

3.2.2. Growth characteristics of introduced bamboos in Ethiopia

3.2.2.1. First entry introduced bamboo species

Associated with variation in the number of species evaluated in the different sites across the country, the number of species assessed varied from site to site (Table 8). DBH and height depend on the species inherent behaviour and also on site growing conditions.

D. Asper

D. asper was tested on two sites (Chagni and Wondo Genet) and showed variation between the sites, although generally, this species had superior performance in all the sites with DBH 7.06–13 cm and height of 19–21 m. The growth also varied from clump to clump, which was mainly associated with introduced management variations, such as cutting part of the offsets heavily from one clump for extracting propagating materials and keeping the other clump intact. For instance, at Chagni, *D. asper* attained a maximum DBH of 10 cm in one clump (undisturbed) but lesser (7 cm) in other disturbed clumps. *D. Asper* showed generally similar DBH and height growth (average DBH 14 cm and average height 16 m) compared to its growth in its origin Southeast Asia (China) (Figure 8).

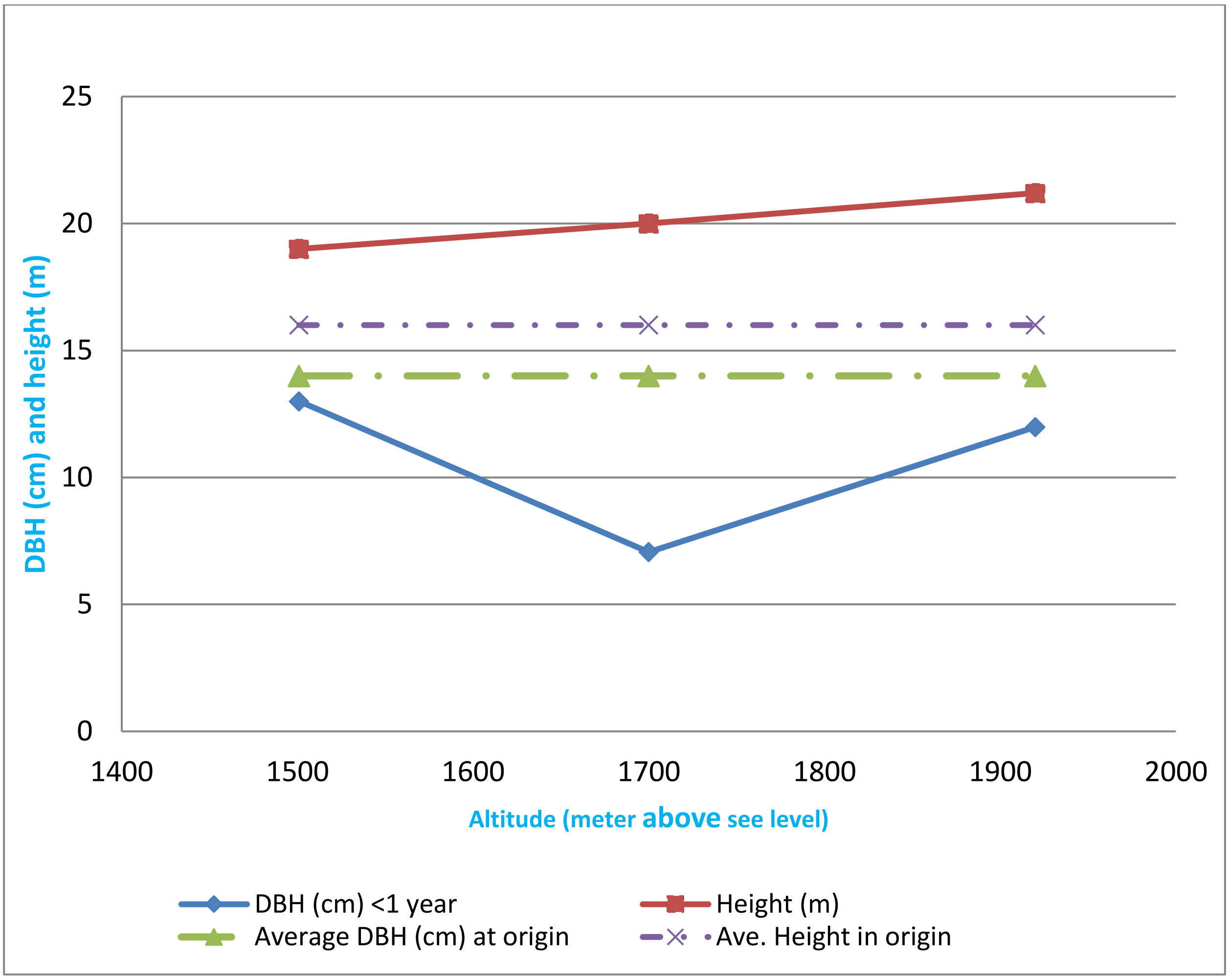


Figure 8: DBH growth of *Dendrocalamus asper* along altitudinal gradient in Ethiopia and across locations (Ethiopia vs. origin)

D. hamiltonii

Similarly, the performance of *D. hamiltonii* tested on three sites also varied from site to site and could be mainly associated with site factors and management variations. DBH and height of *D. hamiltonii* ranged from 7.2 cm to 8.4 cm and 16 to 20 m, respectively, across sites. The performance of *D. hamiltonii* in one of the study sites (Chagni) was disregarded from this comparison because excessive removal of propagules for seedling production highly affected its growth. *D. hamiltonii* showed generally similar DBH and height growth compared to its growth in its origin (Figure 9).

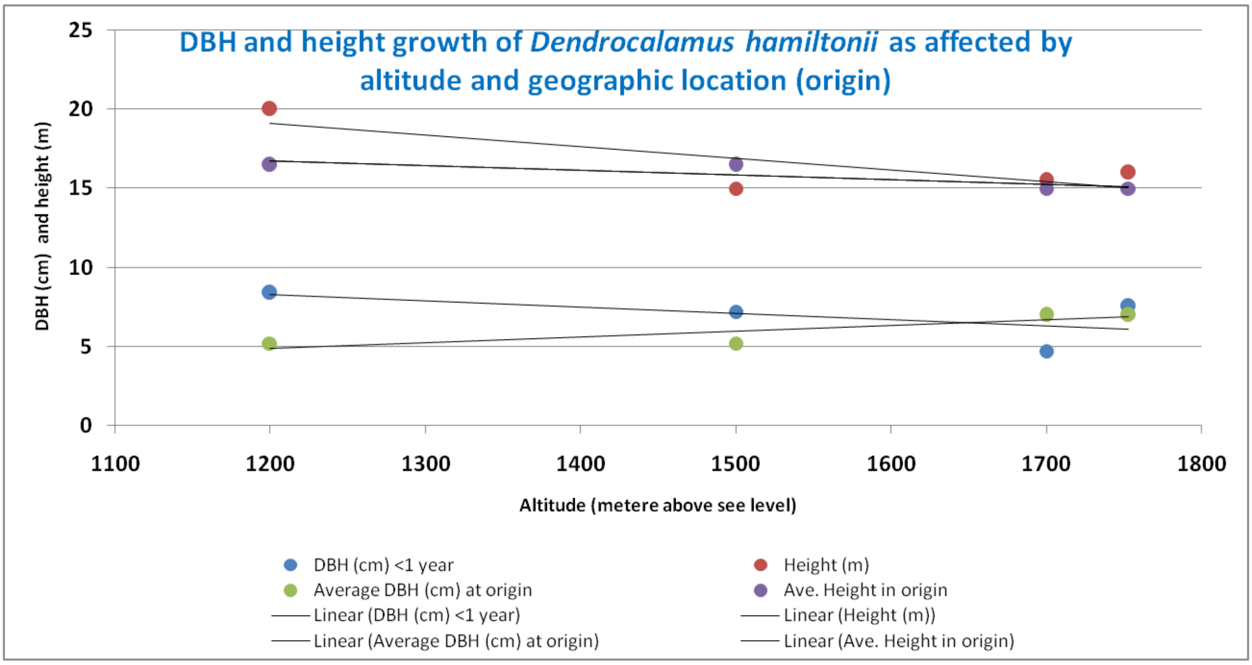


Figure 9: DBH growth of *Dendrocalamius hamiltonii* along altitudinal gradient in Ethiopia and across locations (Ethiopia vs. origin)

D. Membranaceus and B. vulgaris

The DBH and height of *D. membranaceus* varied from 3.2 to 7.3 cm and 12–21 m, respectively, across sites. As compared to its growth at its origin (DBH 17.5 cm and height 12.5 m), Southeast Asia, DBH and height of *D. membranaceus* were lower in Ethiopia (Figure 10). This might be due to management and environmental factors. The DBH and height of *B. vulgaris* (3.5 cm to 8.17 and 13–15 m) can be considered comparable to the growth of the species at its origin, Tropical Asia (DBH 17 cm and height 15 m). DBH and height of *D. membranaceus* and *B. vulgaris* vary greatly among 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 8).

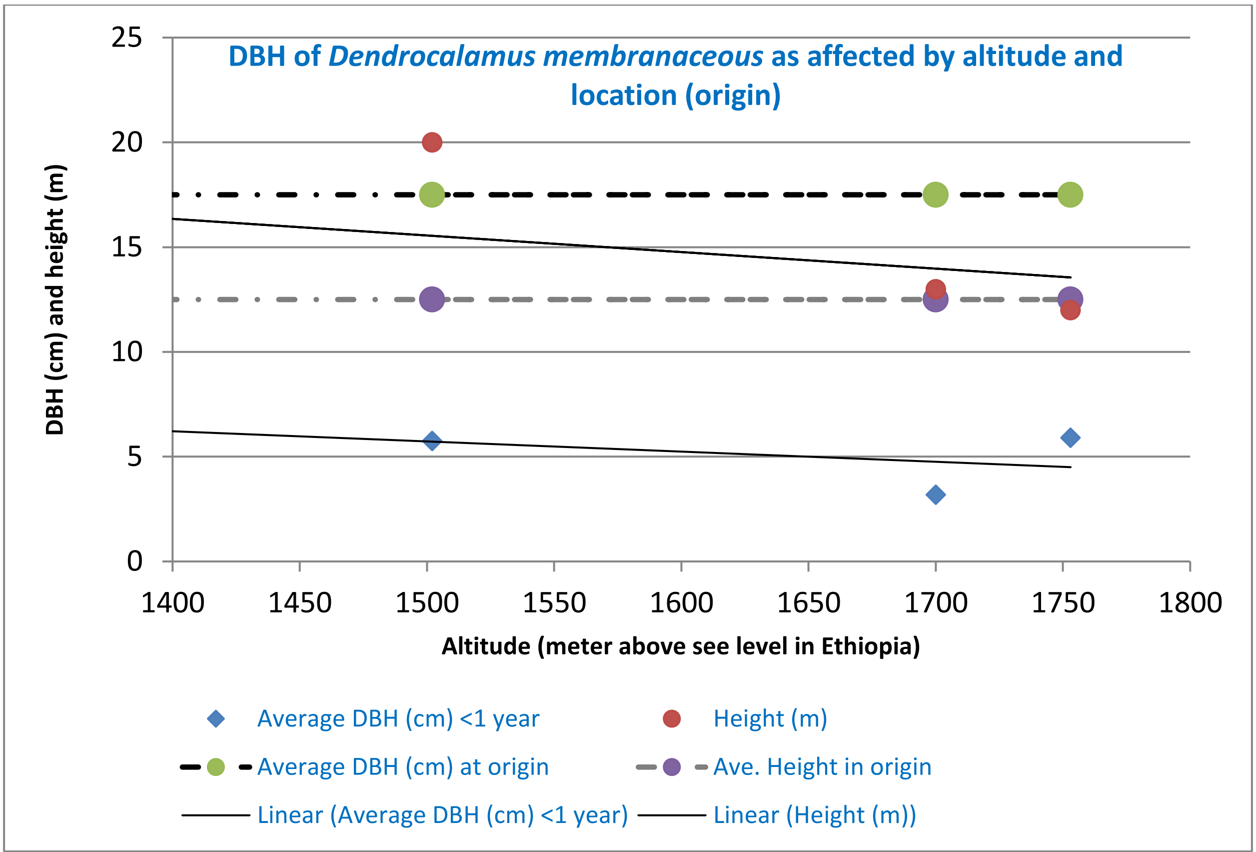


Figure 10: DBH growth of *Dendrocalamus membranaceous* along altitudinal gradient in Ethiopia and across locations (Ethiopia vs. origin)

D. giganteus

The DBH growth of *D. giganteus* (15.13 to 17.88 cm) was lower in Ethiopia as compared to its growth in its origin (Myanmar (Burma), Bhutan, China and Thailand) but similar height growth (20 to 24 m) was recorded (Figure 11).

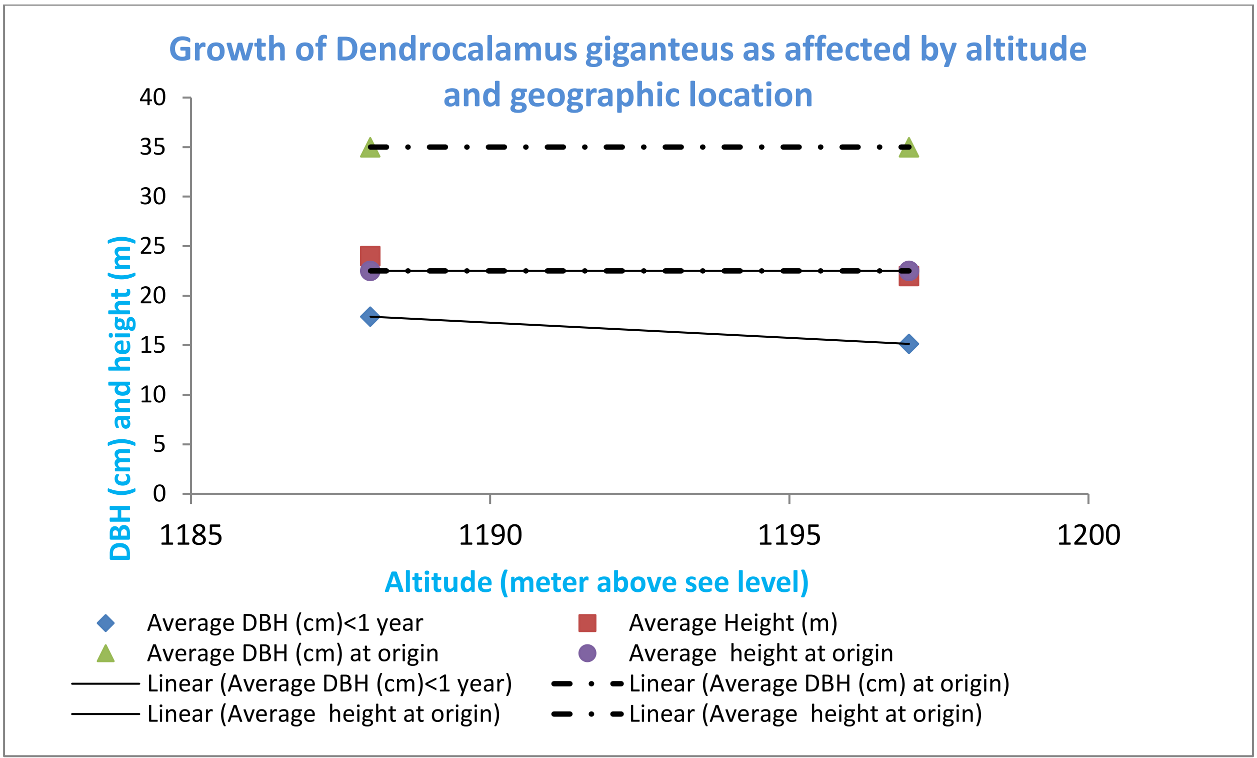


Figure 11: DBH growth of *Dendrocalamus giganteus* along altitudinal gradient in Ethiopia and across locations (Ethiopia vs. origin)

Bambusabambos and B.balcooa

B. bambos performed well under Tepi condition (DBH 7.98 cm and height 16 m); however, observations at Chagni and Pawe revealed that its performance was poor and was, therefore, not considered in this assessment. *B. balcooa* performed well under the Wondo Genet condition but was not assessed in other sites.

Number of culms per clump

The number of culms per clump varied among species and sites. *B. vulgaris* green had the highest number (460) of culms per clump followed by *D. membranaceus* (422 culms per clump), both at the Chagni site (Table 8). *G. amplexifolia* had the least number (17) of culms per clump and also had a low survival rate under Chagni condition.

Table 8: Growth characteristics of introduced bamboo species (average) across testing sites and at their area of origin

S. No.	Research site	Species	Average DBH (cm)			Height (m)	No. of culms/clump	Average DBH (cm) at origin	Average height in origin
			<1 year	1–3 years	>3 years				
1	AbendeMingida	*D. hamiltonii*	7.2	6.87	3.5	15	195	5.2	16.5
2	AbendeMingida	*D. asper*	13	9.7	7	19	50	14*	16
3	AbendeMingida	*D. membranaceus*	5.75	5.4	3.8	20	500	17.5	12.5
4	AbendeMingida	*B. vulgaris*	3.65	2.9	2.2	13	220	7	15
5	AbendeMingida	*B. vulgaris vittata*	5.45	5.7	4.1	16	nd	-	-
6	Arbaminch University Nursery	*D. giganteus*	15.13	11.13	7.34	22	44	35	22.5
8	Chagni	*D. membranaceus*	3.19	2.97	2.75	13	460	17.5	12.5
9	Chagni	*D. hamiltonii*	4.72[4]	3.46*	3.84*	11+	95	7	15
10	Chagni	*D. asper*	7.06 (max 9)	6 (max 10)	6.69 (max 9)	20	214	14	16
11	Chagni	*G. amplexifolia*	7.1	-	4.88	13	17	-	-
12	Chano mile Nursery	*D. giganteus*	17.88	14.44	10.08	24	134	35	22.5
13	Jimma	*D. membranaceus*	5.9?	4.59	4.19	12	190	17.5	12.5
14	Jimma	*D. hamiltonii*	7.53	5.28	4.54	16	225	7	15
15	Tepi	*D. membranaceus*	7.32	4.7	4.28	16+	191	17.5	12.5
16	Tepi	*B. bambos*	7.98	4.98	4.6	16+	170	22.5	27.5
17	Tepi	*B. vulgaris*	8.17	5.47	4.72	15+	171	7	15
18	Tepi	*D. hamiltonii*	8.4	5.82	4.77	20	219	5.2	16.5
19	Wondo Genet	*D. asper*	11.99	7.26	5.63	21.2	58	14	16
20	Wondo Genet	*B. balcooa*	7.77	5.03	-	20	62	-	-

Note: nd = not determined because the species has a loose clumping pattern and it is difficult to define which culms emerged from which rhizome/ clump.

[4]*Growth of D. hamiltonii encountered extraction or excessive removal of propagules for seedling production, hence the value does not explain its performance; early growth was higher than this value; hence, it should not be used for comparison purpose with other sites*

The number of evaluated introduced bamboo species varies from site to site. Site conditions, such as rain fall and temperature, varied greatly in geographic location and climatic conditions. Generally, the results of the assessment indicate that *Dendrocalamus asper, Dendrocalamus hamiltonii, Dendrocalamus giganteus,* and *Bambusa vulgaris* had wider recommended domains similar to the testing sites, whereas *Guadua amplexifolia, Bambusa bambos and Bambusa balcooa* were assessed only on one site. Thus, the recommended domains of these species may be narrow.

3.2.2.2. Status of lately introduced (3rd entry) bamboo species in Ethiopia

In this study, an effort was made to assess the growth performance of 13 bamboo species introduced to Ethiopia on 2 June 2016 from Yunnan (origin) China by the Ministry of Agriculture (MoA) of Ethiopia for the Sustainable Land Management Programme (SLMP II) under a contract signed between INBAR and MoA (Ethiopia Biodiversity Institute, 22 March 2017, Ref. No. EBI 71/7001/2017; MoA Permit No. 1107).

The 13 species introduced were *Dendrocalamus asper, D. yunnanensis, D. fuminensis, D. membranaceus var. Grandis, D. peculiaris, D. barbatus, D. laosensis, D. sinicus, Bambusa longinternode, C. diannanensis, B. polymorpha, B. lapidea*, and *Phyllostachys edulis.* Currently, the species are under nursery and establishment stage in five different woredas (Bibugn, Arbegona, Bambasi, WonchiNeader and Adet woredas) across the country. In Wonchi woreda, *D. asper*, *D. fuminensis and D. yunnanensis* were reportedly (telephone conversation with the assigned SLMP facilitator) performing well since being planted during the 2019 and 2020 rainy seasons as demonstration plots. However, most of them are still maintained in nursery.

In Arbegona woreda, *D. asper* and *D. fuminensis and D.* laosensis performed well two years after being planted on farmer's holdings, communal holdings and under nursery conditions. In Arbegona woreda, six out of nine species germinated under nursery conditions but did not show good growth. Direct field visits made by the consultant in Bambasi woreda, Mender-45 indicated that planting seedlings of the introduced bamboo species was started in 2020, and most seedlings were maintained in the nursery. The introduced species in Bibugn and NeaderAdet woreda have almost similar status. Because of the long-term stay of the introduced bamboo species under nursery conditions and the late start of planting in the field, generating data that shows performance under field conditions was found to be difficult.

4. Reproductive biology of indigenous bamboos of Ethiopia

The lifecycle of bamboo is classified into three main stages: seedling stage, mature stage and reproductive stage (McClure, 1966). The reproductive stage occurs once in its lifetime, age depends on the species, and the plant produces seeds and dies. Despite the negative consequences of bamboo flowering, it is seen as a blessing, in that it provides an opportunity to have genetically more diverse next generation. Typically, bamboo populations are established through vegetative propagations; the reproductive stage is an opportunity to establish bamboo from seeds (Demissew,et al., 2011). Thus, the survival of bamboos after their reproductive stage is dependent on the success of reproduction by regenerating seeds (Yigardu, 2016; Akifumi, 1992). Promoting plantations using the reproductive material, the seed, ensures prominent survival.

4.1. Flowering characteristics and seed procurement of indigenous bamboos

4.1.1. Highland Bamboo (Oldeaniaalpina Syn. Arundiariaalpina; Yushaniaalpina)

4.1.1.1. Flowering characteristics of highland bamboo

Highland bamboo flowers less frequently, with a flowering cycle of about 45 to 50 years. During the last two decades, highland bamboo has been flowering gregariously and sporadically in different administrative zones, including the Dawro, Gedeo, Masha, Kefa and Gamo zones of Ethiopia (Demisse*wet al*., 2011; unpublished reports of EEFRI, 2015; unpublished reports of EFCCC, 2020). Table 9 shows the flowering time and area coverage of highland bamboo stands in different areas from 1990–2020 in Ethiopia.

Table 9: Flowering time and area coverage of highland bamboo stands in different areas from 1990–2020 in Ethiopia

Administrative zone of the flowered site	Woreda, kebele, specific site	Flowering year	Area of flowered forest	Reference
Dawro	Tuta area of Tocha woreda	2009 to 2010	979 ha (66% of the total 1483.25ha)	Sertse *et al*., 2011
Gedeo	Jigo in Bure Woreda	2015 to 2016	300 ha	EEFRI, 2016 report[5]
Sheka	Masha woreda	2008-2011	4,066 ha and more	Mulugeta L., 2013
Kefa	Buta kebele of Adiyo woreda	2020	nd	EFCCC-NFSDP, 2020 report[6]
Gamo	Bonke woreda in Chosha, Denga, Kasheto and KaloGabula kebeles[7]	2020	nd	EFCCC, 2020-NFSDP

nd = not determined

Inflorescence of highland bamboo: paniculate, panicles 10–15 cm long, loose to fairly compact; spikelets 4–11 flowered, linear-elliptic, 1.5–4.8 cm long; glumes ovate; lemmas lanceolate oblong, 0–12 mm long, pubescent, acute, acuminate or awn-pointed (Figure 12, left). The seeds are like the seeds of any other members of the grass family (Figure 12, right), consisting of an endosperm and an embryo comprising a radicle, a plumule and a scutellum.

Figure 12: Inflorescences (left) and seed (right) of highland bamboo (sample collected from Sinan woreda, Choke Mountain, 2012)

[5]*EFCCC-NFSDP(2020). Field report on highland bamboo phenology and seed collection assessment, Tefera Belay (Forest Sector Capacity Building Program).*
[6]*EEFRI, (2016). Assessment on mass death of Ethiopian highland bamboo at Jigo and its surrounding, Bule woreda of Gedeo Zone (YigarduMulatu and others), 26 September 2016.*
[7]*'kebele' is the next lower administrative unit after district, which is the equivalent of peasant association in rural areas of Ethiopia*

4.1.1.2. Phenology of highland bamboo in Ethiopia

Phenology is the study of the relations between seasonal climatic changes, such as temperature, day length, precipitation, and periodic biological phenomena or timing of the reoccurring biological events, such as flowering, fruiting, leaf flushing, and dormancy (Schmidt, 2000). Phenological patterns in plants are influenced by a combination of biotic and abiotic factors that determine the occurrence and inhibition of physiological events (Harrington et al., 1989; Lei and Lechowicz, 1990). Biotic factors are mainly physiological age and abiotic factors, such as stress in climatic and soil conditions, that induce bamboo flowering, which occurs once in its lifetime.

Thus, knowledge of phenological events is useful in developing a proper forest management strategy as well as for a better understanding of forest regeneration potential (Gill et al., 1998). A lack of phenological information limits the understanding of the ecology and evolution of tropical plant species and communities (Dewald and Steiner, 1986). Associated with its rare occurrence, the reproductive stage of bamboo is often regarded as a pandemic by most local people in Ethiopia and probably in other countries.

An assessment and discussions held with the community in southern Ethiopia, Keffa zone, in August 2020 indicated that highland bamboo develops inflorescence during October and November; shedding of inflorescence and fruit initiation stages occur in December and January, followed by seed development or fruiting (Table 10) in the consequent months. June and July are the months for full maturity of seeds (Figure 13). August to November is the time for collecting matured seeds for seedling production purposes.

Table 10: Reproductive phenology of highland bamboo in Southern Ethiopia (Keffa zone) obtained from discussions with the community in August 2020

Phenological stage	**Months**											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Inflorescence												
Shading of inflorescenceand initiation of fruit												
Fruit development												
Seed maturity												
Seed collection												

Figure 13: Seed maturity stage of highland bamboo (top) and seed collection by felling flowered and matured culms (bottom left) and collected seed ready for further processing after long transport (from the Adiyo-Keffa zone to Addis Ababa) in October 2020.

4.1.1.3. Processing highland bamboo seeds

Highland bamboo is a plant of the grass family with small seeds. The seed is a caryopsis with a width of about 0.25 mm and a length of 0.47 mm. Seeds are born within numerous spikelets, each spikelet containing a single seed that forms aggregates or clusters. This type of reproductive structure has made seed processing and cleaning uneasy. As bamboo seed bearing is a rare phenomenon, seed processing machines and tools designed for highland bamboo are scarce. In this study, traditional tools such as wooden mortar and pestle, sieves of different size and sefied[8] (spherical-shaped basketwork) (Figure 14) and seed extraction experience of seed processors at CEE-FRC (Figure 15) were usedto remove pseudospikelets, undeveloped spikelets and other impuritie and to develop aprotocol.

There are two options for purifying lowland bamboo seeds: (1) partially pure (spikelets with well-developed seeds) or (2) pure seeds that have been 100% cleaned of any glumes and impurities. If labour is not a limitation, further purifying partially pure seeds and sowing 100% pure seeds speeds up the time of germination and sowing. A detailed processing protocol was developed and is indicated in Figure 16. Details of highland bamboo seed characteristics are presented in Table 11 below.

[8]*Sefied is a woven material made traditionally of grass; it is a big, flattened plate-like circular material, of radius about 75 cm*

Figure 14: Highland bamboo seed processing tools: =wooden mortar (top right), *sefied* (top, left), sieves of different size (bottom three metal sieves).

Figure 15: Processing of highland bamboo seed: drying (topmost), beating (with optimal force as required) with wooden mortar and pestle (middle left); sieving (middle); winnowing, 100% pure seed (lower left); partially pure seed (bottom right)

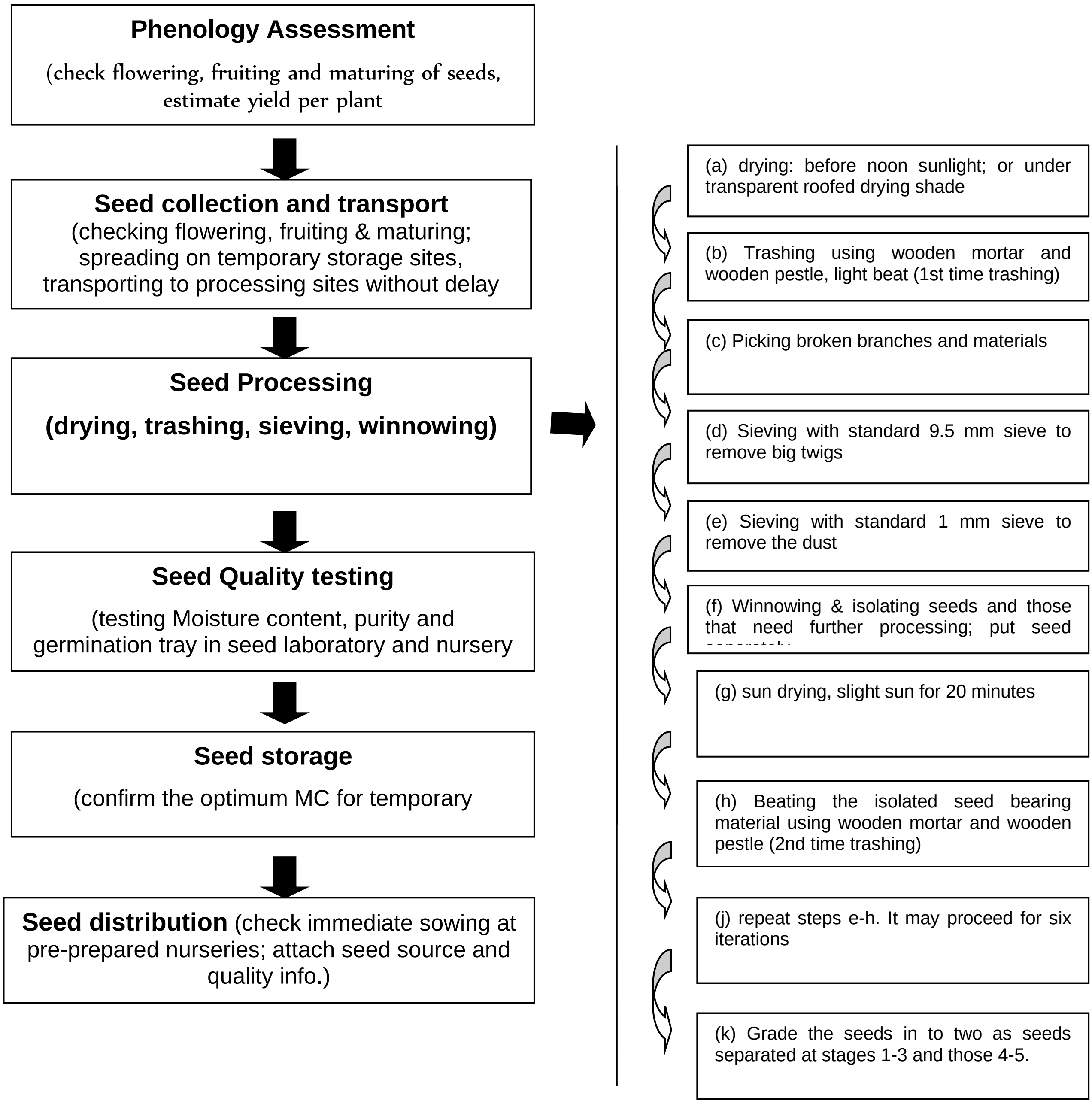


Figure 16: Collection and processing protocol for Ethiopian highland bamboo seed

Note the seed processing method assumed in this protocol is a traditional method, based on indigenous knowledge of Ethiopian seed processors

Table 11: Seed characteristics of highland bamboo

Seed Characteristic	***Measured and estimated values***	***Reference***
		--
Seed Purity	86–91% Depends on the extent of effort applied in cleaning and separating the innermost covers (glumes of the spikelets)	Demelash et al., 2015; Tinsae et al., 2012
MC (fresh seed)	5–8%.[9]	Tinsae, et al., 2012
1000 Seed Weight	17g	Demelash et al., 2015; Tinsae et al., 2012
Number of seed per kilogram	59,416	Demelash et al., 2015; Tinsae et al., 2012
Germination Percentage (fresh Seeds, under controlled/ laboratory, condition)	Up to 73% Often lower than this value, depending on the level of seed maturity	Demelash et al., 2015; Tinsae et al., 2012
Seed size	Seed length 0.59 mm (range 0.1 to 0.2 mm); seed width 0.17 mm (range 0.1 to 0.2 mm).	Tinsae, et al., 2012
Number of seedlings that can be raised from 1 kg seed	37,300 (Under laboratory /controlled condition)	Demelash et al., 2015; Tinsae et al., 2012

Note: Highland bamboo seed does not require pre-sowing seed treatments. Control seeds often have the highest germination rate.

4.1.2. Lowland bamboo (Oxytenantheraabyssinica)

4.1.2.1. Flowering characteristics of lowland bamboo

Lowland bamboo (*Oxytenantheraabyssinica*) flowers in 30- to 35-year intervals in the Benishangul Gumuz region (Demissew, 2011). Discussions with the offices of regional and zonal experts in the Benishangul Gumuz region indicated that sporadic bamboo flowering in the region started in Guba and Mankush woredas (Metekel zone) before 2003 (starting from 1996/1997). Flowering progressed to the Assosa zone (Homosha, Assosa and Bambassi woredas). Flowering in Homosha woreda occurred in 2002–2004, followed by Assosa woreda in a specific locality called Tsetse in 2009 and Bambassi woreda in a specific place called Anbesa Chaka in 2010–2011 (Table 12).

This indicates that flowering occurred progressively. In 2011, flowering was estimated to reach over 85% of the total bamboo cover (previous estimate 400,000 ha; current remote sensing based estimate 947,000 ha) bamboo in the Benishangul Gumuz region (Demissew, 2011). In the field assessment conducted in the Assosa zone in 2020 (under this study), we observed that only two woredas—Mao-Komo and Kemashi—had bamboo stands still flowering. Otherwise, flowering is now in its completion period after 18 years. From the discussions with

[9]*When the collection time is delayed, seed moisture content immediately after collection may go down to 3% with germination percent of up to 53%.*

a limited sample of respondents, thatis by no means comprehensive, we speculate that the wave of bamboo flowering has been progressing from the northern part of the region to its southern part.

Figure 17 shows the different woredas of the Benishangul Gumuz region, from which readers can visualize the progress of bamboo flowering in the region. Further, a detailed survey may provide better mapping of bamboo flowering in the region.

Table 12: Flowering time and area coverage of lowland bamboo stands in different areas from 1990–2020 in Ethiopia

Administrative zone of the flowered site	Woreda, kebele, specific site	Flowering year	Area of flowered forest	Reference
Awi	Jawi woreda, Embasir watershed	1997		
Metekel	Guba woreda, Mankush woreda	1996, 1997, 2000	nd	Regional office, discussion with experts
Assosa	Homosha woreda	2002–2004	nd	
	Assosa woreda, specific site called TseTse	2009	nd	Regional office, discussion with experts
	Bambassi woreda, specific site called Anbesa Chaka	2010–2011	nd	Demissew, 2011
Kemashi	Kemashi	Still flowering (2020)	nd	Field assessment, 2020
Mao-Komo special woreda	Mao-Komo special woreda	Still flowering (2020)	nd	Field assessment, 2020

nd=not determined

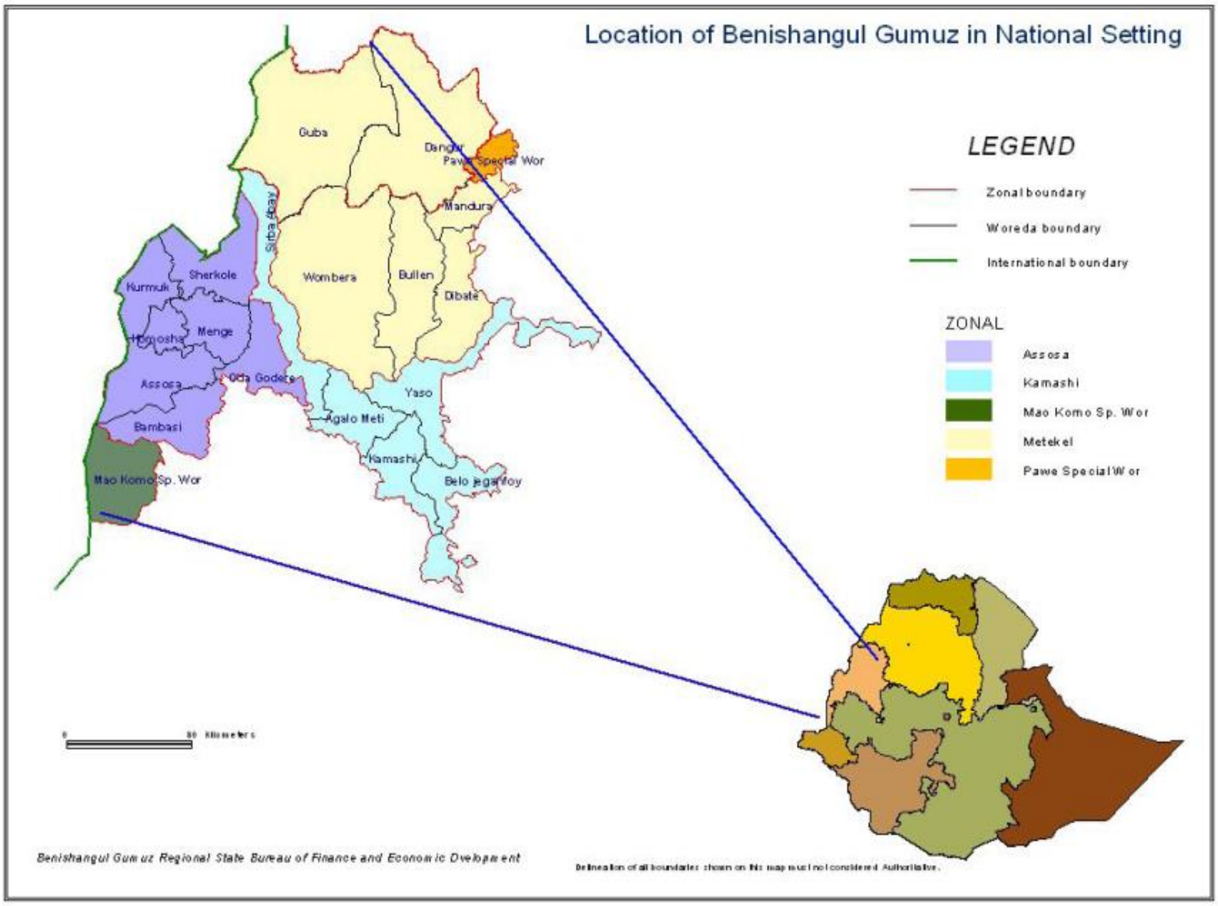


Figure 17: Relative location of the three zones (Metekel, Assosa and Kemashi) of Benishangul Gumuz region in Ethiopia, where gregarious bamboo flowering has been progressing for the last 18 years

Following discussions on the major lowland bamboo growing areas in Ethiopia, a field visit was made in August 2020 to Buldigilu Gambisheri kebele of Assosa woreda, Benishangul Gumuz region, northwest Ethiopia, where the remaining (probably the last stand together with the one currently flowering in Mao-Komo woreda) lowland bamboo is flowering. A discussion was held with a lowland bamboo seed supplier in the region, who collected and distributed lowland bamboo seed. The nature of flowering, time for flowering-fruiting-seed maturity, and seed collection methods were discussed, and photographs were captured.

Inflorescence of lowland bamboo

When *O. abyssinica* flowers, all growing points (every leafy branch and terminals) develop into a flowering shoot, and the leaves turn brown and gradually drop off. Each branch develops the flowering units (pseudo spikelet or spikelet) at its node and apices (Figures 18,19). A flowering culm has all of its originally leafy branches transformed into flowering shoots, and buds at culm and branch nodes can also develop directly into pseudo spikelet clusters.

The fruits are arranged into aggregates that are composed of spikelets. Fruits are also spiny at one end, opposite to the embryo, which poses a problem for collection and processing. The inflorescence is a dense star-shaped cluster 4–9 cm in diameter, with 10–20 spikelets (Figure 19). Spikelets are sessile, narrowly lanceolate, 1.5–4.5 cm long, pungent, 1–4 flowers with upper floret, bisexual, and lower florets male or sterile; lower glume 5–8 mm long, upper glume 8–10 mm long, lemma narrowly lanceolate, the lowest 12–20 mm long, tapering into a rigid spine up to 7 mm long, palea narrowly lanceolate, somewhat shorter than lemma; floret with 6 stamens, filaments unite into a tube, and a glabrous ovary extend into a hollow style terminating in three stigmas. Its fruit is a spindle-shaped caryopsis, 10–15 mm long.

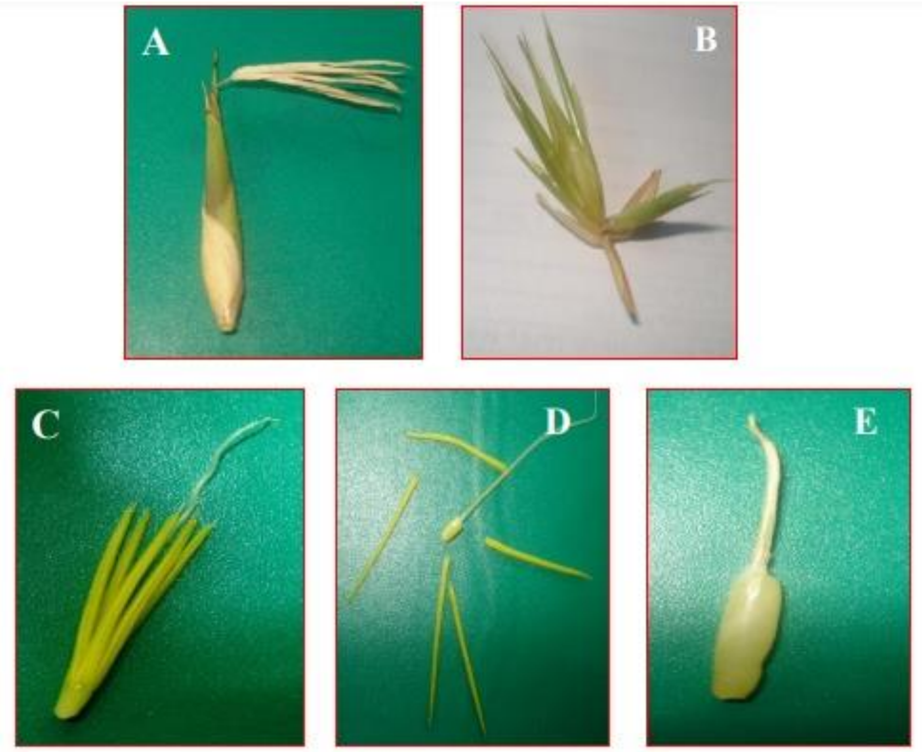


Figure 18: Single spikelet of *O. abyssinica* fruit (A) and seed covering (B), female and male parts of a flower (C), parts of a flower separated into components (D), developed ovary (E)

Figure 19: Flowered clump (A), flowered fruit aggregates (B), fruit aggregates after petals removed (C), petals (D).

4.1.2.2. Phenology and seed collection of lowland bamboo

An assessment and discussion with the community in northwestern Ethiopia (Assosa woreda, BuldigluGambisheri PA) in October 2020 indicated that lowland bamboo flowers during July and August. Shedding of flowers and fruit initiation stages happen in August, followed by seed development or fruiting from August and September (Table 13; Figure 20). October and November are the months for full maturity of seeds. December to February is the time for both the first round and second round collection of matured seeds for seedling production purposes.

Table 13: Phenological calendar of Ethiopian lowland bamboo in northwestern Ethiopia, 2020

Phenological stage	**Month**											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flower initiation						■	■					
Flower shading							■	■				
Fruit initiation (setting)								■				
Fruit growing								■	■			
Fruit ripping (maturity)										■	■	
Seed collection	■	■										■

Figure 20: Flowered clump (right), fruit development stage, manually bent flowering culm ready for seed collection (left); seed collection from a single culm is conducted twice; whichis, clusters at thebottom branches (to the right of the dashed vertical arrow) along the culm height are collected first and clusters at the upper branches (to the left of the dashed vertical arrow) are collected next.

4.1.2.3. Collection and processing of lowland bamboo

After the maturity of the seed is confirmed, seed collection begins. It is advisable that a minimum of three seed collectors do the collection simultaneously. This is because seeds along the culm height do not mature at the same time. The fruits at the lower portion mature two to three weeks ahead of the fruits at the upper portion of the culm. Hence, while collecting seed from a mother plant, one collector needs to hold the culm (Figure 20, left; Figure 21), bending so that the other two collectors, carrying receiving bags in front wearing thick plastic gloves on their hands to protect their hand from the thorny tips of spikelets, do the picking of matured fruits (clusters).

Afterwards, collected fruits need to be moved to storage places using carts or vehicles. For sites that are inaccessible for carts or vehicles, the use of human and animal power becomes compulsory to transport the collected fruit to accessible sites.

The collected fruits from collection sites are then spread on concrete floors or canvases, exposing them to sunlight for about two days. During the night, the fruit should be mounded and covered to avoid moisture absorption. After two days of drying, the fruit is checked for dryness. Once the fruits are sufficiently dried, they are agitated using *sefied*[10]so that the bigger sized fruits be on top and the small and pseudo spikelets remain under; the bigger sized spikelets are then ready for sale or distribution. If distribution is supposed to be delayed for more than a week, the good quality fruits need to be temporarily maintained in a cool and dry place. Detailed seed collection and processing protocol for Ethiopian lowland bamboo developed in consultation with seed processors at Assosa is presented in Figure 22.

It is important to note that seed size and the number of glumes enclosing seeds of highland bamboo and lowland bamboo vary. As the seed size of lowland bamboo is large and easily accessible by external pressure like beating, there is a need to take care while separating the seed from the glumes. Applying mechanical force on spikelets of lowland bamboo, such as beating the fruits with wooden mortar and pestle, as in the case of highland bamboo spikelets, to separate the seed results in crashing and breakdown of the seeds. Highland bamboo has more spikelets in the inflorescence, each with its seed (if not pseudospikelet) and glumes. Besides, much of the spikelets in highland bamboo are empty; hence, support is reducing the effects of applied forces, beating, during seed extraction. Detailed seed characteristics of lowland bamboo are provided in Table 14.

[10]*Sefied is a woven material made traditionally of grass; it is a big, flattened plate-like circular material, of radius about 75 cm*

Figure 21: Seed processing of lowland bamboo: matured clusters (topmost), picking matured clusters with hand (left, middle), sun drying collected spikelets (left, bottom and right, top); extracting the clusters, removing glumes and winnowing (right, middle); partially pure and 100% pure seeds (right, bottom)

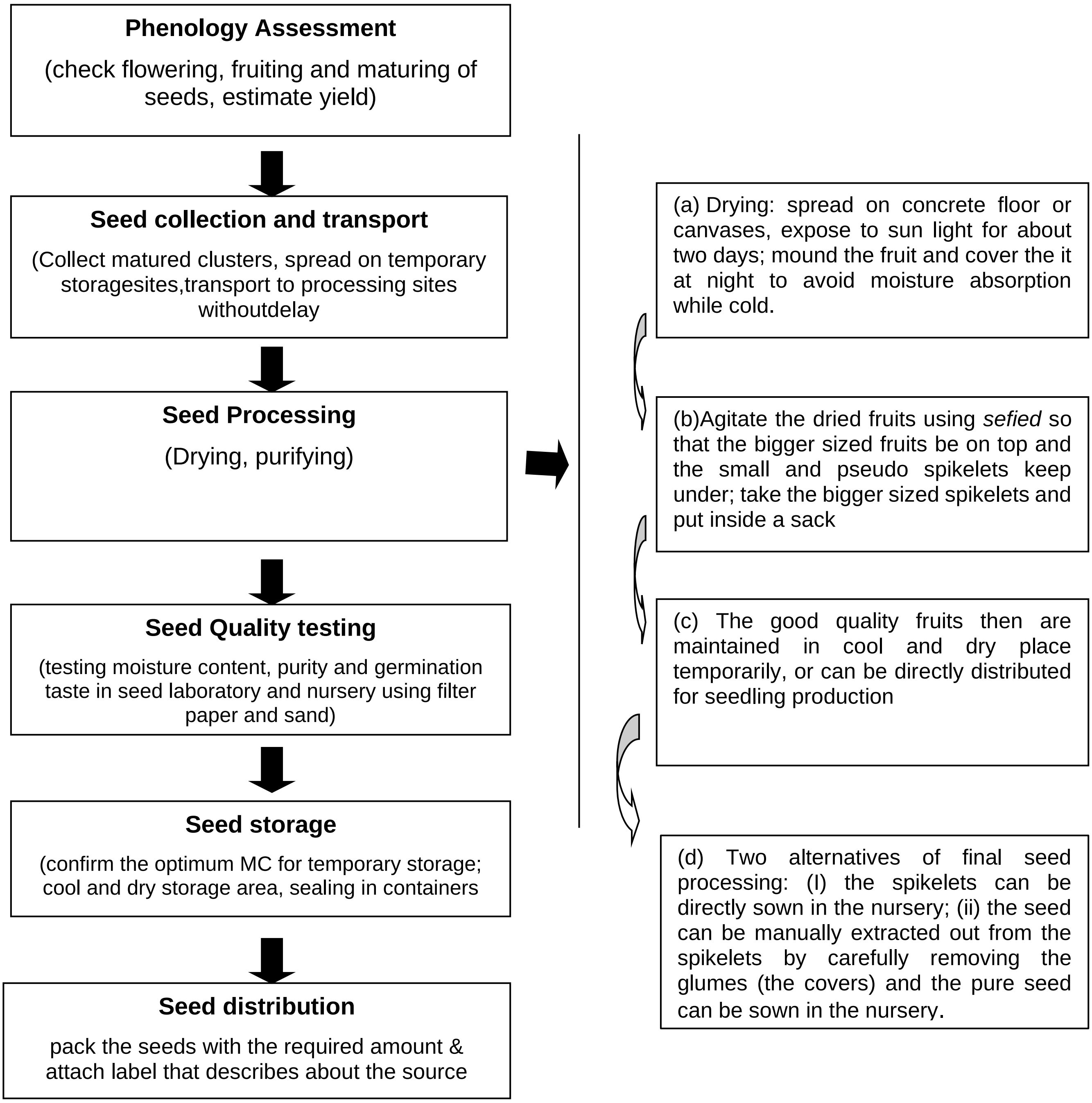


Figure 22: Seed collection and processing protocol for Ethiopian lowland bamboo

Note the seed processing method followed by bamboo seed collectors in Ethiopia.

Table 14: Seed characteristics of lowland bamboo

Seed Characteristic	Measured and estimated values	Reference
Seed Purity	78–91%	Demelash et al., 2015; Tinsae et al., 2012
MC (fresh seed)	4–7%	Tinsae, et al., 2012
1000 Seed weight	85–120 g	Demelash et al., 2015; Tinsae et al., 2012
Number of seed per kilogram	8,000–11,500; depends on the location or forest land use type, indicating effects of environment and extent of fertilization	Demelash et al., 2015; Tinsae et al., 2012
Germination percentage (fresh seeds, under controlled/laboratory, condition)	84.5% during the 11-day period after sowing.; May reach 98% in 15 days under laboratory condition[11].	Demelash et al., 2015; Tinsae et al., 2012
Seed size	Seed length 1.60 cm (range 1.2 to 1.9 cm); seed width 0.31 cm (range 0.2 to 0.4 cm),	Tinsae et al., 2012
Number of seedlings that can be raised from 1 kg seed	7,000–8,880 (under laboratory/controlled condition);	Demelash et al., 2015; Tinsae et al., 2012

Note: Lowland bamboo seeds do not require pre-sowing seed treatments. Control seeds had the best germination rate.

4.1.3. Pest and disease of indigenous bamboo seeds

A report (Demelash *et al*. 2015) indicated that seed borers and fungi affect fruits and seeds of *O. abyssinica*, but the organism type was not identified. The seed borers (white) were found to develop inside the seed. The occurrence of such diseases and pests varied with collection sites. Detailed research needs to be conducted on the disease and pests of *O. abyssinica* and fruits and seeds. The susceptibility of *O. abyssinica* seeds to damping-off fungus during germination is very critical; hence, aeration and maintaining appropriate moisture of the germination media is required. Determining optimum watering frequency, which depends on the climatic conditions of the area, and making the germination media not too wet while watering should be given due attention during seed germination either in field or laboratory. The literature review conducted in this study indicated that research on pests and disease of *O. alpina* is limited, hence, it needs consideration.

4.1.4. Storage

Seeds of highland bamboo stay viable only for a few months. Observation indicated that germination rate drops by more than 50% in five months. Because of this poor viability, seeds need to be collected and sown in nursery without delay. Nevertheless, fresh seeds having the highest germination rate, *O. abyssinica* can retain its viability for about two years (Demelash et al., 2012) by using traditional storage media. Storing seeds in a cold room of +10°C, elongates viability for up to three years (Tinsae et al., 2015); hence, the local people can

[11]*Under nursery conditions, day to start germination may be delayed up to 9-12 days (source: Dereso, 2019)*

collect as many seeds as possible and use them for establishing bamboo plantations for any purpose. Traditional storage media and storage time have a significant impact on the germination and field emergence of O. abyssinica seeds. Better seed germination and field emergence results were observed in seeds stored in glass bottle and plastic bottles, implying that these storage media are better traditional means of storing bamboo seeds. By contrast, storing bamboo seeds in traditional storage media that have large openings, such as sisal sacks, results in high deterioration of the seeds within a short period. Therefore, airtight traditional storage media are better at maintaining the viability of bamboo seeds for longer periods. Since there is high humidity and temperature in lowland bamboo growing areas, the use of sacks and other containers which have many openings results in high deterioration of *O. abyssinica* seeds (Demelash et al., 2012).

5. Identification of clumps/culms for seed sourcing

5.1 What are the best planting material sources for bamboo?

The quality of the forests in the future depends on the quality of seedlings planted today; selecting a good seed source results in a high quality product. Similar to animals and other plants, the genetic characteristics of bamboo provide the variation by careful selection of the source of seed or planting material. The different bamboo populations in Ethiopia can provide a good foundation for seed sources.

Associated with its monocarpic nature of flowering, bamboo is propagated primarily by vegetative means. Thus, mother stock or starting materials for seedling production in bamboos are both vegetative materials, such as offsets (rhizome-based techniques), cuttings (branch, culm), or seed. A seed/vegetative material source (or simply a seed source) is where seed (including vegetative materials) is collected, which is not necessarily a stand. This may be an identified number of clumps in the agricultural landscape, natural forest, or plantation forest.

A good seed/vegetative material source should provide fast-growing, healthy, good size (DBH, height, wall thickness, internodal length, straightness) or high biomass productivity for energy applications or leaf if the species is intended for leaf production, genetically diverse seed and stable planting material. The age of the seed source (flowering cycle) is a critical factor when selecting seed sources and planting materials, as it gives information about the time of flowering and consequent death of the future stand sourced from it. Thus, superior clumps should also be carefully selected for seed collection because the offspring produced from the source resembles the selected mother clump, therefore capturing the potential advantage of reproducing the mother plant (Banik, 1993).

Seed of the highest quality may be very expensive; thus, there is a need to balance quality and cost for planting purposes. To match the species with the environmental conditions of the planting site, it is always safe to collect seeds locally or nearby from clumps that are well adapted to the environmental conditions of the planting site and satisfy the aforementioned quality standards.

5.2 Selection of mother clumps as seed sources

Prior to seed collection, there is a need to select and mark good mother clumps. These are the clumps that will be used as sources of high-quality seeds. Here are the major criteria that determine a good mother clump:

1. Healthy and free of diseases and insects
2. Good producers of the desired product
3. Growing in the midst of a healthy stand of the same species.

As there are many culms in a clump, culms where seed would later be collected need to be carefully selected. At this stage, culms that bear well-developed fruit along the culm height and are unaffected by pest and disease should be selected.

Naturally, associated with access to light, growing space, and precipitation, seed bearing varies among culms in a clump, although culms that are at the peripheries of clumps bear more fruits because they have relatively good access to ecophysiological resources.

Seed collection can be done in two ways: (1) on standing culm, by bending; (2) by felling the selected seed bearing culm. Bamboo culms normally die after flowering and seed bearing. Thus, with prior agreement with the owner of the bamboo forest, culms selected for seed collection can be felled and the seed can easily be collected with easy access.

5.3 Guideline for identification of suitable mother clump for seed and vegetative material production.

When seed is the planting material, it is required to check its genetic, physical, and physiological qualities. The number and quality of clumps should ensure wide genetic variation and seed quality. To maintain genetic diversity, therefore, a lot of seeds need to be collected from at least 30 flowered mother clumps. Moreover, in certain areas with similar soil, topographic and management conditions, clumps of big diameter and height need to be selected for seed collection. For species such as *Dendrocalamus hamiltonii* that are selected for their leaf, selecting clumps that have more leaves is required.

General suitability criteria for evaluating areas designated for seed sources could include:

(1) Is the seed source in the right ecological zone where seedling production and planting will be carried out?

(2) Is the size of the seed source and number of mother clumps adequate?
(3) Are age, size, form, and shape of mother plants superior?
(4) Does the seed source fulfil utilization criteria for intended uses?
(5) Are the clumps healthy, and do they have good performance?
(6) Is the accessibility and security of the seed source appropriate?
(7) Will the plants be pollinated?
(8) How good are surrounding plants of the selected clump that could be parents of the seeds that will be collected and thus affect the quality of the progeny.

5.4 Criteria for selection of superior bamboo species for different end uses

In this study, the distribution of indigenous and introduced bamboo species was investigated. The structure of stands, such as age composition, culm DBH, culm height, and internodal length, were investigated.

Indigenous knowledge of the community in Ethiopia indicates that application of highland bamboo landraces for different components of a single product varies. A good example is the experience of handicrafts of the Choke Mountain people, who are engaged in basketry. The handicrafts' men use "Tifro[12]" landrace of highland bamboo, which is rigid in its workability as walls of baskets, while "Wolele" landrace of the same species, which is flexible as thread to be woven over the walls. Culm walls of "Tifro" landrace have a higher proportion of fibre and a lower proportion of vascular bundles, while culm walls of "Wolele" landrace has lower proportion of fibre and a higher proportion of vascular bundles (laboratory observation on bamboo anatomy, Yigardu, 2012).

There is variation in utilization aspects between the two indigenous species. Culms of lowland bamboo are often solid and in some cases partially solid. Lowland bamboo isoften recommended for pulp and paper production and bio energy purposes. Currently, it is observed that this species is used to a lesser extent for making handicrafts. Board making using lowland bamboo needs specialized machines to split and process the solid/semi solid culms.

[12]*"Tifro" is a landrace of highland bamboo that has nails (Tifr in Amharic = nail) in each internode along the culm height.*

Highland bamboo, a hollow bamboo but with a thick culm wall, is highly used for producing many industrial products in Ethiopia as compared to lowland bamboo. The two actively functioning medium-sized modern industries in Ethiopia (Adal Industrial LTD and SA Bamboo PLC) produce bamboo boards, curtains, mats, toothpicks and incense sticks from highland bamboo.

Laboratory research conducted as a collaboration between the MoA-East African Bamboo Project and the Forest Research Institute of Malaysia (FRIM) indicated that both highland and lowland bamboo can be used for manufacturing industrial products, such as ply board, laminated bamboo lumber (LBL), oriented strand board (OSB), medium density fibre board (MDF) and floor boards (FRIM, 2008).

Thus, a thorough understanding of anatomic and growth characteristic bamboo species and variation within a single species is required while planning the establishment of bamboo stands.

Industry applications

- The two indigenous bamboo species of Ethiopia are good industrial species. *O. alpina* is preferred for boar-based and stick-based products; *O. abyssinica* deserves promotion for pulp and paper and energy production.
- *D. asper* can be promoted for structural timber (strong, large, very good quality) and for heavy construction in rural communities. The species is relatively durable. It is also used in making good-quality furniture.
- *D. gigantus*and *D. membranaceous* should be accorded for house building, fencing, good quality furniture, pulp and paper and handicrafts.
- *B. vulgaris* is used for a variety of purposes, primarily for light construction, such as houses, huts, fences, scaffolding for climbing cash crops, furniture, musical instruments and handicrafts.

Bioenergy application

- *O. abyssinica*, which grows aggressively and with solid/semi solid culms, should be accorded for bioenergy production. This species can be promoted in lowland areas of northwest Ethiopia and around the investigated sites in this study for biomass energy.

Fodder production

D. hamiltonii has high (about 20%) carbon allocation to leaves (Asabeneh et al, 2015). The species also has good organic matter and crude protein and can be used for animal feed substitution (Fikremariam et al, 2019; Eyob et al., 2017)

Edible shoots

- Ethiopian indigenous bamboo species, *O. alpina* and *O. abyssinica*,have good mineral and nutrient composition, as described by Yigardu et al. (2020); hence, it can also be promoted and managed for their edible shoots.
- *Dendrocalamus asper*, also known as 'Sweet Bamboo', is the most widely accepted species globally for edible shoots Chandramoulia et al., 2014). As its growth performance is superior among the many tested introduced bamboo species in Ethiopia, the prospects of cultivating the species for its shoots should be high.
- Similarly, *D. hamiltonii* can be promoted for its edible shoots.

5.5 Seed sourcing from outside the country

It is possible that plants raised from seed that is collected from a site with different conditions will still perform well when planted under our condition. This is why some research institutions undertake trials in different locations to test how plants from one location perform at others. Sometimes, plants perform even better under conditions that are different from those of their natural environment. However, we need to have prior knowledge of the performance of the provenance in their origin. In such cases, there is a need to obtain genetic material permits and introduce good quality seeds from abroad following the established procedure.

The main issues to focus on here are:

- Identifying suitable local or international seed suppliers (please see Table 15)
- Obtaining Material Import Permit from the Ethiopian Biodiversity Institute (EBI), specifying detailed objectives of the seed/planting material import.
- Sending out request for the seed you need with specifications of the species, when you need the seed, how many plants you need to raise and description of the environment at the site where the seed is to be planted. Send out the request well in advance of the planting period.

Genetic Material Import Permit applicants in Ethiopia need to fulfil the following (http://www.ebi.gov.et/gm-access/gm/). These are:

- Official letter from the import requesting organization,
- A revised and authenticated copy of the research proposal (not more than 15 pages) – with brief introduction, objective/s, expected outcomes and the benefit of the research to Ethiopia.
- In the official letter, the person/Institute responsible for the research, local and scientific name of the species that needs to be imported, amount of sample in grams/kilograms/packs etc., the country from where the material is imported, total number of accessions/samples and purpose of the research need to be mentioned.
- The passport data and/or pedigree information of the samples needs to be attached to the official request letter.
- Five (5) copies of signed material transfer agreement (MTA) by the importing organization and/or the researcher need to be produced along with the official letter for faster facilitation process. The MTA will be made between the importing organization and EBI.

Table 15: Origin and international seed suppliers for introduced bamboo species

No.	Species	Origin of species	Seed supplier
1	*Dendrocalamushamiltonii*	South Asian countries such as India, Sri Lanka, Bhutan, Nepal, Pakistan, and far eastern China	Sugatu Global, Dehradun, Uttarakhand, India and also from eBay
2	*Dendrocalamusmembranaceus*	Southeast Asia	Heartwood seeds.co.uk, eBay , amazon.com
3	*Dendrocalamus asper*	Southeast Asia (china)	Amazon. Com, rarepalms.com, eBay
4	*Dendrocalamus giganteus*	Myanmar (Burma), Bhutan, China and Thailand	Sugatu Global, Dehradun, Uttarakhand, India, Floral Seed Company
5	*Bambusa vulgaris*	Tropical Asia	Mother Herbs (P) Ltd, New Delhi, Delhi, Amazon.com
6	*Bambusabambos*	Southern Asia (India, Bangladesh, Sri Lanka, Vietnam, Cambodia, and Laos)	Sugatu Global, Dehradun, Uttarakhand, India, Mazon.com

5.6 Propagation of indigenous bamboos in Ethiopia

5.6.1. Propagation by seed

Highland bamboo and lowland bamboo can be propagated through seedlings produced from seeds collected as prescribed in the previous section. Detailed procedure on propagating bamboo from seed is described by Yigardu and Asabeneh (2016) and Durai and Long (2020) (https://www.eefri.gov.et;https://www.inbar.int/resources/inbar_publications/manual-for-sustainable-management-of-clumping-bamboo-forest/) and summarized in Table 16.

5.6.2. Propagation using wildlings

If wildlings or naturally growing indigenous bamboo seedlings in the forests are available, these can be collected and used as planting materials.

5.6.3. Propagation by using rhizome-based methods

As seeds and seedlings are not often available, the most common way of propagating indigenous bamboo is by offsetting a bamboo plant from a clump. After severing and separating a bamboo plant from the clump, the top portion is cut out and the big portion that comprises the rhizome and culm (the offset) is planted. The advantage of this technique, compared to many other methods, is the shorter time it takes for the newly established stand to reach a matured plantation state with full-sized culms. The disadvantage of the method is, however, its labour intensiveness; hence, it is difficult to apply for large-scale planting. Thus, research recommended rhizome-based methods: rhizome + culm with two internodes (or called stamp) and rhizome+four internodes and rhizome+six internodes, are suggested as the other vegetative propagation strategy for indigenous bamboo species in Ethiopia (Yigardu, 2016; Yared, 2018).

5.6.4. Macro-proliferation

When seeds or wildlings are not available and a large quantity of planting materials is required, the method of offsets should be integrated in a nursery macro-proliferation programme. Division of plants and producing as many seedlings in the nursery as required on site provide a means for lowering overall costs. At the nursery, the procedure developed by different authors, including Yigardu et al.(2016b) and Durai and Long (2020), can be followed.

5.6.5. Propagation using tissue culture

Tissue culture is an advanced method of propagating lowland bamboo on a large scale. Commercial tissue culture is done in laboratories that need to produce and sell mass quantities of plants for economic viability. Research on tissue culture production of lowland bamboo in Bahir Dar (ORDA-Organization for Rehabilitation and Development in Amhara Region) tissue culture laboratory in Ethiopia showed success in mass propagation of lowland bamboo for large-scale planting. EEFRI and two universities (Selale University and Debre Markos University) are producing lowland bamboo seedlings (in 2020) by a tissue culture method jointly with ORDA to establish large-scale lowland bamboo plantations in 2021 along big rivers in Ethiopia.

Table 16: Comparative advantages of the different propagation methods of indigenous bamboos in using vegetative techniques and seed Ethiopia

Propagation Methods	Planting materials used	Advantages	Disadvantages	Method reference
Propagation by seed	Bamboo seeds	Large scale	Hard to get seed; takes long time to reach mature state	Ronald, 2005; Yigardu and Asabeneh, 2016;
Propagation using wildlings	wildlings	Genetic quality	Small scale; Takes a long time to reach mature state	
Rhizome-based methods	Rhizome with attached culm of different size	Faster to reach mature stand	Small-scale, labour intensive	Yared et al., 2017; Yigardu and Masresha, 2014
Macro-proliferation	Bamboo seedlings	Large-scale	Takes long time to reach mature state	Yigardu et al. (2016b); Durai and Long (2020); Ronald, 2005
Whole culm method	The whole plant, with reduced leaf and rhizome	Can be used to obtain starting materials for macro-proliferation and field planting	Small scale; demand wide space to propagate	Yigardu and Masresha, 2014
Tissue culture		large-scale	Expensive and	

Note: *the two indigenous bamboo species (Highland bamboo and Lowland bamboo) do not respond to the propagation methods called culm cutting and branch cutting. Despite shooting has been possible using cuttings, difficulty in root development has been found as a challenge to these methods for the two indigenous species.*

5.7 Propagation of introduced bamboo species across indigenous bamboo growing areas of Ethiopia

5.7.1. Vegetative propagation

Introduced species of bamboo, including *Dendrocalamus hamiltonii, Dendrocalamus membranaceus, Bambusa vulgaris, Dendrocalamus asper, Dendrocalamus giganteus* and *Bambusa bambos* were propagated by culm cutting, branch cutting and macro proliferation methods (Table 17).

Table 17: Propagation of introduced species using vegetative techniques and seed at nursery level

Name of species	**Culm cutting**	**Offset**	**Branch cutting**	**Rhizome–based)**	**Rhizome cuttings**	**Whole culm**	**Seed**	**Macro proliferation**
Dendrocalamus asper	√	√						√
Dendrocalamus hamiltonii	√	√	√	√		√	√	√
Dendrocalamus giganteus	√	√	√	√	√	√		√
Bambusa vulgaris var. green	√	√		-	-	-		√
Dendrocalamus membranaceous	√	√	-	-	-	-	√	√
Guadua amplexifolia		√						
Bambusa bambos	√	√		√				√
Bambusa balcooa	√	√	√	√				

Note: (-) sign indicates that the response of shooting and rooting for the specified material needs to be checked further.

5.8 Packaging/handling bamboo seeds

- Seeds shall be packed only in sound, clean and dry containers made of jute or cloth with suitable inner lining of laminated polyethylene or poly propylene or high density polyethylene bags, pouches or any other packaging material.
- The container shall be free from any insect infestation or fungal contamination and also free from any undesirable or obnoxious smell.
- Seed shall be packed in such a way as to protect the produce properly. The container shall be securely closed and sealed.
- The materials used inside the package must be clean and of such a quality as to avoid causing any external or internal damage to the produce.
- Each package shall contain the specified seed of one grade designation only. Suitable number or small packets of the specified seed containing graded material of the same lot or batch and grade.
- Designation may be packed in a master container, such as jute bags, wooden cases, and cardboard cartons, with details on the master container.
- Seeds shall be packed in the pack sizes as per marketing agreement.

5.9 Labelling and distributing seed

At the time of seed distribution, basic information about the see source and quality aspects of the seed need to be labelled on the seed. Annex I shows details of the required information (passport data) that need to provided, that help tracing ecological, climate and vegetation conditions of the seed source, with the seed that is distributed to other areas for further bamboo planting. Moreover, extracted information need to be provided in the tag that is attached with the seed. Information that should be labelled in the tag include:

- Name of the producer;
- Botanical name of the species
- Geographic location of the seed source
- Geographic location of the original seed source in the case of a seed orchard or seed production unit
- Ecology of the seed source (elevation, temperature, rainfall, soil type)
- Ecology of the original seed source in the case of a seed orchard or seed production unit
- Number of plants/clumps in the seed source
- Size of the seed source
- Age of the seed source.

6. Conclusion and recommendation

In this study, scientific information on growth, distribution, reproductive biology, and seed source selection criteria of bamboo species in Ethiopia was generated. Accordingly, growth (DBH, height) of lowland bamboo across environmental factors (elevation and climate) showed that promoting lowland bamboo in lower altitude areas having average minimum temperature (as low as 10.4°C) is recommendable. However, areas of higher altitudes (e.g., 2979 masl) and annual temperature values (as low as min. 5.3°C, and as high as average max. 24.2°C), with annual rainfall range from 1123 mm to 2458.32 mm can promote highland bamboo in Ethiopia. Introduced species, such as *D. asper*, *D. hamiltonii* and *D. gigantues* have shown similar performances in Ethiopia compared to their growth in their areas of origin. *D. membranaceus* and *B. vulgaris*, showed slightly lower growth in Ethiopia compared to their growth in their areas of origin. Generally, the results of the assessment indicate that *Dendrocalamus asper, Dendrocalamus hamiltonii, Dendrocalamus giganteus,* and *Bambusa vulgaris* have wider recommended domains in Ethiopia that are similar to the studied sites, whereas *Guadua amplexifolia, Bambusa bambos* and *Bambusa balcooa* were assessed only on single site, which narrows the recommended domains of the species at the moment.

Seed collection and processing protocols for Ethiopian lowland bamboo and highland bamboo are developed based on traditional methods and indigenous knowledge of Ethiopian seed processors. Besides, a guideline is developed for the selection of superior clumps/culms that are used to obtain vegetative materials at the time of bamboo planting using asexual methods and collect seeds during bamboo flowering. Vegetative propagation techniques of the two indigenous and five well-performing introduced bamboo species were also provided for the use to actors in bamboo development in Ethiopia.

Further study is recommended in the following areas:

- Detailed mapping of bamboo flowering in Ethiopia
- Identify altitudinal and climate limits of indigenous bamboos

Finally, the author recommends that all actors engaged in promoting bamboo plantations in Ethiopia use this technical guide.

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8. Annexes

Annex 1. A standard format for passport data sheet (adopted for bamboos) [as adopted by NBPGR from FAO, IPGRI and Hawkes (1980)].

PASSPORT DATA SHEET

Expedition/Organization:					
Team/collector(s):		Date:		Collector no.:	
Species name:		Common name:			
Vernacular name:		Accession no.:			
Region explored:		Country:		State:	
Distt.:		Block/village:			
Latitude:	°N	Longitude:	°E	Altitude:	m
	°S		°W		

SOURCE: 1. Natural wild ___2. Disturbed wild ____3. Plantation__ 4. Village groves ______5.Private garden____

STATUS: 1. Wild ___2. Weedy ____3. Cultivated________

FREQUENCY: 1. Abundant________2. Frequent_________3. Occasional_______4. Rare ______

MATERIAL: 1. Rhizomes___2. Culms_____ 3. Inflorescence_____ 4. Roots_____ 5. Live Plants 6. Herbarium________7. Others_____

SAMPLE TYPE: 1. Population______2. Few plants_______3. Individual plan___________

SAMPLE METHOD: 1. Bulk________2.Random__________ 3.Selective_________ (non-random)_____

HABITAT: 1. Forest ________2.Disturbedforest____3.Partlydisturbed____ 4. ………

PLANTCHARACTERISTICS:…………………………………..

....

....

ADDITIONAL NOTES: ………………………………………………………….

....

.....

USES: ....

....

....

CULTURAL RACTICES:	1. Irrigated .... 2. Rainfed .... 3. Arid .... 4. Wet...........5 (other) ....

SEASON: 1. Spring-Summer 2. Autumn 3. Winter

SOIL CHARACTERISTICS:

SOIL COLOUR: 1. Black ___2. Yellow ____3. Red ______4. Brown_____ 5……….

TEXTURE: 1. Sand_________2. Sandy loam_______ 3. Loam_____ 4. Silt loam__

5.Clay 6. Clay loam________ 7. Silt _______8…………

STONINESS: 1. Stony 2. Pulverized 3.

DRAINAGE: 1. Well drained ______ 2. Poorly drained __________3………

pH.: 1. Normal 2. Alkaline_________ 3. Acidic

LANDFORM:

ASPECT: 1. Level _________2. Crest______ 3. Escarpment______ 4. Rounded summit_

______ 5. Upper summit___________ 6___________

SLOPE: 1. Mild slope_______ 2. Lower slope______ 3. Open depression________4.Closed depression_________ 5. Terrace__________

TOPOGRAPHY: 1. Swamp________ 2. Flood plain ______ 3. Level_____ 4. Undulating_

______ 5. Hilly dissected__________ 6. Steeply dissected_______ 7. Mountainous

______8.Valley______

PLANT COMMUNITY

ASSOCIATED: ……………………………………………………………….

....

.....

MAJOR SPECIES

ASSOCIATED: ………………………………………………………………..

....

....

NAME OF

COLLECTOR: ………………………………………………………………………

....

.....

COLLECTION NO. AND OTHER

DETAILS: …………………………………………………………...

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