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Technical Paper

Exotic Bamboo Species in Kenya: Identification and Assessment

Muralidharan Enarth Maviton[1], Gordon Sigu[2], Magrate Kaigongi[2], Nellie Oduor[3], Robert Sunya[3], Selim Reza[3], Durai Jayaraman[3]

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[1] Independent Consultant

[2] Kenya Forestry Research Institute, Kenya

[3] International Bamboo and Rattan Organization

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About the International Bamboo and Rattan Organization

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

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International Bamboo and Rattan Organization

P.O. Box 100102-86, Beijing 100102, China

Tel: +86 10 64706161; Fax: +86 10 6470 2166

Email: info@inbar.int

www.inbar.int

Foreword

The two species that make up the native bamboo resources of Kenya are underutilized and limited to traditional applications, such as rural buildings, handicrafts, and household products. As a versatile, environmentally friendly, rapidly renewable, and sustainable alternative to timber, bamboo has established its credentials in many countries around the world. Several exotic bamboo species have been introduced in the past into Kenya but bamboo's potential as a means of generating employment and contributing to the economy and environment was largely ignored until recently. The country has an insignificant share of the global trade in bamboo. However, the private sector in the country has shown a surge of interest in bamboo-based enterprises that promises an increasing role for the bamboo sector in the Kenyan economy. In recent years, it has been globally recognized that bamboo could contribute directly to at least seven of the UN Sustainable Development Goals (SDGs): SDG 1 (No poverty), SDG 7 (Affordable and clean energy), SDG 11 (Sustainable cities and communities), SDG 12 (Sustainable consumption and production), SDG 13 (Climate Action), SDG 15 (Life on land), and SDG 17 South–South cooperation). The potential of bamboo as a tool for climate change mitigation efforts and benefits through carbon credits is also widely recognized.

Since the 1980s, several exotic species of bamboo have been introduced into Kenya, and several agencies, including the Kenya Forestry Research Institute, have conducted trials in various regions. The scientific capability related to bamboo taxonomy and identification of exotic species, their phenological characteristics, origins of planting materials, and potential uses is limited in Kenya. The Dutch–Sino East Africa Bamboo Development Programme: Phase II of INBAR, initiated in 2017 in Ethiopia, Kenya, and Uganda, has pursued the objective of transferring the knowledge gained from global experiences in the use of bamboo as a tool to improve livelihoods. A field study to identify the introduced species in different locations in Kenya and assess their performance was undertaken under this program in November 2022. The study is expected to fill gaps in knowledge and help select the most suitable species for the different agroecological zones and for various applications that can contribute to the economic development of the country.

This report on the identification and assessment of exotic bamboo species in Kenya is expected to overcome many of the current limitations and help realize the full potential of bamboo to bring about a transformation in the economy of the country. It is anticipated that a proper understanding of the different species and their potential for utilization will encourage greater involvement of government agencies, research organizations, farmers, and

entrepreneurs in taking up bamboo plantations of the best species, and that scientific management will ensure higher productivity and more efficient utilization.

Ali Mchumo
Director General

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Authors

Table of Contents

List of Tables

List of Figures

Executive summary

In addition to the two species native to the region, the bamboo resources of Kenya consist of several exotic species that were introduced into the country in the past decades. Because the introductions and trials carried out in the different regions were not systematically documented, it has not been possible to derive a significant amount of information to assess the potential of each species and to select the best performers to adopt for future large-scale plantations. Field visits were made to different trial sites and plantations of exotic species in Kenya to assess their performances in different agroecological zones (AEZs).

Conventional taxonomy depends on the characteristics of the floral parts. This imposes a severe restriction in the case of bamboo, because most species flower only once in their lifetime; during most of the intervening period, identification has to depend only on vegetative characteristics. To overcome this serious limitation, a field key to species identification, suitable for laypeople and based on vegetative morphological features, was developed. Descriptions of the selected exotic species of Kenya given in the report include taxonomic information that includes the valid name, synonyms, and common names of the species, a description of the morphological features that can help in identification, the climatic parameters ideal for the species, propagation and cultivation methods, productivity, and uses. Photographs, which also help identify the species, include the clump and culm habits, as well as the branching pattern and the appearance of new shoots and culm sheaths.

The observations made during the field visits and the typical characteristics of the exotic species in their native habitats were used to assess the suitability of selected exotic species to the different AEZs of Kenya (Infonet-Biovision, 2023).

The thorny species *Bambusa bambos* was found most suitable for AEZs CL2–4 and LM1–2, but is also expected to perform well in AEZs UM1–2 and LH3 up to 1,600 m above sea level (ASL). Regular pruning of thorny branches is essential to keep the clumps in manageable condition and to improve the productivity and quality of culms. *Bambusa spinosa* (*B. blumeana*), another thorny species, is suited to AEZs CL2–4, LM1–3, and UM1–2 from sea level up to 2000 m.a.s.l; management practices similar to those for *B. bambos* are recommended.

Bambusa multiplex, a small bamboo, is suitable for both lower and higher elevations in AEZs LM1–3 and UM1–2.

Bambusa polymorpha and *Bambusa tulda*, both medium-sized species, are most suited for AEZs LM1–3 between 100 and 1500 m.a.s.l and UM 1–2 between 100 and 1700 m.a.s.l.

Bambusa vulgaris, the pan-global species, was found to be suitable for most zones, particularly where soil moisture is not a constraint. It is best suited for AEZs CL2–4, LM 2–3, and UM1-2 from sea level up to 2000 m.a.s.l. Although the yellow variety was more commonly found, the green variety is recommended because its superior properties and durability are preferred.

Among the larger bamboo species, *Dendrocalamus asper* is most suited for AEZs CL2, LM1–2, and LH3 from sea level to 2000 m.a.s.l. *Dendrocalamus brandisii* was found best suited for the humid areas of AEZs LM1–2, LH3, and UM1–2 from sea level to 2000 m.a.s.l, while *Dendrocalamus giganteus*, a large diameter species, was suitable for cultivation in AEZs LM1–2, LH3, and UM1–2 in areas with reliable rainfall from sea level up to 2100 m. ASL.

Dendrocalamus hamiltonii and *Dendrocalamus membranaceus*, medium-sized bamboos, were best for AEZs CL2–4, LM1–2, LH3, and UM2 zones with reliable rainfall from sea level to 2000 m.a.s.l and 1800 m.a.s.l, respectively.

Dendrocalamus strictus, a small bamboo adapted for drier areas, would be suitable for AEZs LM 3–5 and CL 2–4 from sea level up to 1000 m.a.s.l. *Thyrsostachys siamensis*, another small species, is suitable for AEZs L2–4 and LM2 from sea level to 2000 m.a.s.l.

The running bamboo species *Phyllostachys aurea* is best suited to AEZs LM1–2, UM1–3, and LH1–3, up to 2100 m.a.s.l.

Recommendations derived from the study indicate the steps to be taken before large-scale plantations are undertaken to exploit the full potential of bamboo. Demonstration trials with suitable germplasms of the selected species are to be carried out with experimentation of spacing and management practices, including agroforestry options with the main agricultural crops of each AEZ. These can be followed by standardization of large-scale clonal propagation methods for the best-performing clones for the production of quality planting material. It is also recommended that a certification scheme for ensuring quality planting materials and nursery management be adopted.

1. Introduction

Bamboo, the woody perennial grass, has recently attained importance primarily as the source of rapidly renewable wood biomass for a range of applications that contribute to sustainable development. The benefits of bamboo lie in its contributions to the environment and the economy, which include the plant itself in its natural or cultivated form, its traditional use in construction and handicrafts as an alternative to timber, steel, and plastics, its use as a processed or engineered food, and its use as a viable bioenergy feedstock.

Bamboo is found in three major geographic regions with tropical and subtropical climates—South and Southeast Asia, Africa, and Central and South America (Latin America). All three regions have their native species, and several of them have been brought into large-scale cultivation. Introductions to other regions have also been attempted, with varying levels of success. Southeast Asia and China are extraordinarily rich in species diversity, and, unsurprisingly, many species are cultivated in the region and as exotics in other regions.

Bamboo forest is estimated to cover an area of 1310.40 km^2 in Kenya (Zhao et al, 2018). Most of this is highland bamboo (*Oldeania alpina*), found mainly on Mount Elgon and Mount Kenya, and in the Cherangany Hills, the Mau Forest, and the Aberdare Range. In East Africa and other regions in Africa, exotic bamboo species have been introduced since the early twentieth century. More recent introductions were made as part of species trials in which as many as 22 species were planted in different locations (John et al, 2022). In recent years, the multiple uses of bamboo, especially its industrial applications, have generated awareness around the world and led to interest in the commercial cultivation of both native and exotic species. Apart from the traditional knowledge about bamboo, associated with the uses that it has been put to in rural communities, potential farmers and entrepreneurs often lack information on scientific cultivation, management, harvesting, and utilization.

The challenges

Bamboo was formally recognized as a cash crop in Kenya in 2020 to encourage its commercial exploitation and use for improving green cover. This is sure to renew the interest in bamboo plantations, but also highlights the gap in information on species and cultivation practices. The use of bamboo to increase forest cover will go a long way toward meeting the nation's commitments to the Bonn Challenge, the African Forest Landscape Restoration Initiative, the United Nations Sustainable Development Goals (SDGs), the Convention on Biological Diversity, and the United Nations Framework Convention on Climate Change.

The introduction of exotic species of bamboo into the country without appropriate documentation has resulted in confusion regarding species identity as well as the origin of planting material. The later introductions were part of trials carried out in various locations, and the expectation was that growth performance would generate information that could inform future plantation programs. However, the absence of proper management of clumps in trials has resulted in suboptimal performance. The existing resource of native and introduced species in Kenya has been studied by John et al (2022).

A better understanding of the taxonomy of bamboo species, especially exotic species, is advantageous to its cultivation and utilization. Identification of bamboo from planting material produced in the nurseries is fraught with the risk of misidentification. We made field visits to areas of concentration of bamboo to observe morphological variations and growth performance, attempting to identify the species precisely and make an identification key. Based on these observations and the literature on experience in other countries, we recommend matches between species and sites.

Classical taxonomy depends heavily on the characteristic features of reproductive parts. However, the gregarious flowering nature of many of the important bamboo species and their long lifecycles are great hurdles because no flowers are available for identification during most of the plants' lifetimes. Although bamboo species have been discriminated through descriptions of the reproductive parts, bamboo has traditionally been identified through vegetative characteristics. Variations in morphological characteristics between different provenances within the species, compounded by interactions with local climatic factors, make identification based on features such as color and texture difficult.

2. Methodology

Introduction of exotic bamboo species into Kenya and establishment of plantations in different locations were done at various time points since the early 1990s. Since the field performance of the species were not documented consistently, it was necessary to undertake field visits to all known trial locations to make first hand observations.

The history of introductions was reconstructed as best as possible from the records available in public domain and from official files in the organizations involved in the species trials and plantations.

Field visits to the major AEZs in Kenya was done in November 2022. At the locations with private plantations or experimental trials, the bamboo clumps were observed closely to identify morphological features that could help in identification. In the absence of flowers and new shoots at the time of the field visit, only the morphological features of the culms could be used in identification of the species along with information provided by the farmer or official managing the plots. The microclimatic factors in the location as well as the general climatic factors and management regimes adopted were noted so as to identify the influence of such factors on growth.

The literature on the exotic species was consulted to collect information on the distribution range, species characteristics and native habitat, climatic factors and utilization. This information together with the actual performance in Kenya was expected to help in taking decisions on the suitability of a particular species to the potential sites across the different agroecological zones in the country.

3. Agroecological zones of Kenya

The variety of landscapes and climatic and soil parameters across the country, as well as the diversity of crops being cultivated, have led to the classification of different agroecological zones (AEZs) in Kenya (Infonet-Biovision, 2023). Since the main parameters for agricultural and horticultural crops are relevant to bamboo cultivation, it is useful to assign the suitability of different species to the AEZs in Kenya with varying climatic factors (Table-1).

Table 1. Classification of different Agroecological Zones (AEZs) in Kenya (Adapted from John et al. (2022)

County	AEZ	Elevation (m)	Annual mean temp (°C)	Annual rainfall (mm)
I. Central highlands				
Kiambu	LH1	2,085	16	1,067
Kiambu	LH3	2,070	15.9	954
Murang'a	UM1	2,056	18–19	1,600–1,800
Nyeri	UM2	1,757	18	933
II. Western Kenya				
Kakamega	UM1	1,633	20.5	2,100
Migori	LM2	1,504	21.7	1,400
Busia	LM1	1,227	22.2	1,600
III. Semi-arid eastern Kenya				
Kibwezi	LM5	945	22.6	659
IV. Coastal lowlands				
Kwale	CL2	66	27	1,386
Kilifi	CL4	25–85	27	927–1059

LH = Lower highland zone (LH1—tea zone; LH3—wheat, maize zone)
UM = Upper midland zone (UM1 [humid]—tea and coffee zone; UM2 [sub-humid]—mainly coffee zone)
LM = Lower midland zone (LM1 [humid]—sugarcane zone ; LM2 [sub-humid] —marginal sugarcane zone; LM5 [semi-arid]—millet zone)
CL = Coastal lowland zone (CL2 [humid] —marginal sugarcane zone; CL4 [sub-humid]—cashew nut and cassava zone)

4. Exotic bamboo species of Kenya

Over a span of two decades, the Kenya Forestry Research Institute (KEFRI) has implemented a collaborative effort with development partners to introduce a total of 14-15 exotic bamboo species throughout various agroclimatic zones. The species were carefully monitored under the diligent oversight of the field offices of the Kenya Forestry Research Institute (KEFRI) at designated trial plantation locations. According to the official records, the subsequent exotic species were recorded and observed in the field for the purpose of assessment and identification(Table-2).

Table 2. Exotic bamboo species found in Kenya

Bambusa bambos	***Dendrocalamus brandisii***
Bambusa multiplex	***Dendrocalamus giganteus***
Bambusa polymorpha	***Dendrocalamus hamiltonii***
Bambusa spinosa (B. blumeana)	***Dendrocalamus membranaceus***
Bambusa tulda	***Dendrocalamus strictus***
Bambusa vulgaris	***Thyrsostachys siamensis***
Dendrocalamus asper	***Phyllostachys aurea***

4.1. *Bambusa bambos* (L.) Voss

Synonyms (Vorontsova et al., 2016):

Arundo bambos L., *Bambos arundo* J.F. Gmel., *Arundo excelsa* Salisb., *Bambusa indica* André, *Arundarbor bambos* (L.) Kuntze, *Bambusa bambusa* Huth, *Bambos bambos* (L.) W.F. Wright, *Arundo arborea* Mill., *Bambos arundinacea* Retz., *Bambusa arundinacea* (Retz.) Willd, *Bambos quinqueflora* Stokes, *Nastus arundinaceus* (Retz.) Sm., *Arundarbor arundinacea* (Retz.) Kuntze, *Arundo agrestis* Lour., *Bambos agrestis* (Lour.) Poir., *Bambusa agrestis* (Lour.) Steud., *Arundarbor agrestis* (Lour.) Kuntze, *Arundo bambu* Lour., *Arundo indica* Noronha, *Arundo maxima* Lour., *Bambos maxima* Poir., *Bambusa maxima* (Poir.) Steud., *Gigantochloa maxima* (Poir.) Kurz, *Arundarbor maxima* (Poir.) Kuntze, *Bambusa orientalis* Nees, *Ischurochloa arundinacea* var. *orientalis* (Nees) Buse, *Arundarbor orientalis* (Nees) Kuntze, *Bambusa arundinacea* var. *orientalis* (Nees) Gamble, *Bambusa arundo* Wight ex Steud., *Bambusa neesiana* Arn. ex Munro, *Bambusa arundinacea* var. *gigantea* Bahadur, *Bambusa bambos* var. *gigantea* (Bahadur) Benn. & R.C. Gaur, *Bambusa bambos* f. *gigantea* (Bahadur) S.S. Jain & S. Biswas.

Common names (Language/Area in parentheses):

Thorny bamboo (English); *Kotoha bah* (Assam-India); *Wakynta (*Garo-India); *Kanta baun*s (Orissa-India); *Illi, Mula, Pattill* (Kerala-India); *Bidduru, Gatte* (Karnataka-India); *Toncur* (Gujarat-India); *Bongu veduru, Mulla veduru* (Andhra Pradesh-India); *Mungil* (Tamil Nadu-India); *Nal bans* (Punjab-India); *Kanta bans, Behor bans* (West Bengal-India), *Kanta bans* (Bangladesh); *Kante bans* (Nepal); *Katu Una* (Sri Lanka); *Cha-kat-wa, Kyakat-wa* (Burmese); *Phai Paak, Phai Namm* (Thailand); *Rai-sai* (Khmer); *May Phaipa, Phaix pa* (Laos); *Russei khlei, Russei prei* (Cambodia); *Tre Ng, Tre Gai* (Viet Nam); *Bambu duriori* (Indonesia); *Pring ori* (Jawa-Indonesia); Indian bamboo (Philippines); Spiny bamboo, *Bambú espinoso* (Cuba); *Banbu cafi a de indios* (Spanish); *Bambus, Dorniger* (Germany); *Bambou épineux* (French).

Description:

A large clumping evergreen bamboo with short-necked pachymorph rhizomes. Culms are erect or gently arching. Culms are 6–10 m high (Banik, 2016) with a diameter of 5–8 cm, wall thickness 1–1.5 mm, and internode length of 20–40 cm. Branches armed with stout thorns are a characteristic feature of this species. The culm sheath is wide, triangular with pointed tip, 16–18 cm long and 16–18 cm broad, adaxial surface glabrous or sparsely minutely hairy in stripes, abaxial surface, glabrous, margins glabrous, hyaline, filmy, in median region of sheath

upper margin slightly upwards. Ligule coriaceous, small, margin in equal position, and auricle indistinct from ligule(Figure-1).

Distribution:

A. Native range:

Indian Subcontinent to Indo-China

Indian Subcontinent: Assam, Bangladesh, India, Sri Lanka

Indo-China: Cambodia, Laos, Myanmar, Thailand, Viet Nam

India: Orissa, Madhya Pradesh, Konkan, and in the Western Ghat Range, Jharkhand, Bihar and Chhattisgarh, Deccan, Nilgiris

B. In cultivation/naturalized in:

Western Indian Ocean: Seychelles

Indian Subcontinent: Maldives

Malesia: Jawa, Malaya, Maluku, Philippines, Sumatera

Central America: Costa Rica, El Salvador, Honduras, Nicaragua, Panama

Caribbean: Cuba, Windward Islands

Locations in Kenya: Kilifi-Jilore, experimental plot (AEZ-CL4);

Migori-Kehancha, private plantation (AEZ-LM2)

Climatic parameters:

B. bambos is native from sea level up to elevations of 1200 m (Banik, 2016), with approximately 2000–2500 mm annual rainfall and mean maximum temperatures of 28.5–36.7°C. The species grows well in red to brown laterite and sandy loam soil with pH 7.4–7.8. In Kenya, the species is found growing from 25-1504 m.a.s.l in areas with annual rainfall 927 -1400 mm, mean annual temperature of 22-27°C and sandy to sandy clay soils.

Native habitat:

This species is native to humid tropics in moist and dry deciduous forests, degraded forests along riverbanks, in river valleys, and in other moist sites (Banik, 2016).

Propagation:

B. bambos flowers gregariously in cycles of 30–49 y. Seed weight (Number in 1 g) is estimated as 99 (Banik, 2016), and 50–80% germination is obtained. Clonal propagation through macro proliferation is widely practiced (Kumar, 1994). Rhizome offsets of 1–2-year-old culms give

65–75% success (Banik, 2016). Hormone-treated culm cuttings give 50–60% rootbring and branch cuttings 45–65% success (Banik, 2016). Air layering is also feasible (Banik, 2016), but not commonly practiced. Propagation through tissue culture is reported in the species through both axillary bud proliferation (Arya et al, 2002) and somatic embryogenesis (Mehta, Rao and Mohan Ram, 1982).

Cultivation:

Spacing of 5 × 5 m or 6 × 6 m is used for block plantations, while 3–4 rows at close spacing is suitable for live fencing. Mixing with species such as Teak is possible (Banik, 2016).

Productivity:

Culm production: 16 culms per clump at the end of six years after planting (Shanmughavel and Francis, 1993). Mean annual biomass production was 49.6tDMha−1, over the 6 year period.

Uses:

Traditional uses: handicraft, weaving, culm for construction, edible shoots, thorny branches for fencing, and clumps for live fencing (Banik, 2016), and medicinal amorphous siliceous deposits (Tabashir) (Banik, 2016). Good potential industrial uses: laminated bamboo, strand woven, paper pulp, biorefinery, and charcoal. Water and soil conservation. Food for wildlife (elephants). In Kenya, the species is mostly used for rehabilitation of degraded land and for live fencing.

Figure 1. *Bambusa bambos*: a) Clump habit; b) Culms and thorny branches; c) New shoot; d) Culm sheath; e) Culm surface

4.2. *Bambusa multiplex* (Lour.) Raeusch. ex Schult.f.

Subspecies/varieties/clones:

Fern leaf, Alphonse-Karr, *B. multiplex* var. *multiplex* (*xiao shun zhu* or *yuan bian zhong*), *Bambusa multiplex* var. *incana* B. M. Yang (*mao feng huang zhu*), *Bambusa multiplex* var. *riviereorum* Maire (*guan yin zhu*), *Bambusa multiplex* var. *shimadae* (Hayata) Sasaki (*shi jiao zhu*).

Common names (Language/area in parentheses):

Xiao shun zhu (China); Chinese dwarf bamboo, Clumping bamboo, Hedge bamboo, Oriental bamboo (English).

Description:

A densely clumped bamboo with short-necked pachymorph rhizomes and arching tips. The height of the culm reaches 3–10 m, with a culm diameter of 1.5–3 cm. The internodes are 30–45 cm long, and the wall thickness is 0.3–0.8 mm. Nodes are slightly prominent, with branching throughout the culm. Culms and branches are green-striped, green, or yellow, with branches at culm nodes from the base to the top(Figure-2).

Distribution:

A. Native range:

China: China South Central, Hainan, China Southeast

Indian Subcontinent: East Himalaya, Nepal

Indo-China: Laos, Myanmar, Viet Nam

B. In cultivation/naturalized in:

Western Indian Ocean: Mauritius, Madagascar, Seychelles

Western Asia: Iraq

Indian Subcontinent: Bangladesh, Pakistan, Sri Lanka

Indo-China: Cambodia

Malesia: Malaysia

Papuasia: Bismarck Archipelago

New Zealand: New Zealand North

Southeastern U.S.A.: Florida

Mexico: Mexico Southeast

Caribbean: Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, Windward Islands

Western South America: Colombia, Ecuador

Brazil: Brazil Southeast

In Kenya, it is found in Muranga-Gatanga private plot in AEZ-UM1

Climatic parameters:

B. multiplex grows at a wide range of temperatures from −10 °C to 42 °C, in areas with an annual rainfall of 800–2500 mm and at elevations of 5–1000 m. In Kenya it is reported in cultivation at elevations of 2056 m.a.s.l and with mean annual rainfall 1600-1800 mm and mean annual temp 18-19 °C

Soil:

The species prefers well-drained medium (loamy) and heavy (clay) soils. Soil organic carbon of 0.80–1.50% and a pH of 4.30-7.10 are suitable for the cultivation of this species.

Native habitat:

The species is found wild and under cultivation on low hills, mountains, riversides, and in fields.

Propagation:

The species flowers rarely and has not been reported to set seeds. Clonal propagation is widely used through culm and branch cuttings and rhizome offsets. Tissue culture procedures for multiplication using shoot meristems (Shirin and Rana, 2007) and somatic embryogenesis (Yuan et al, 2010) have been reported, but commercial methods are not known.

Cultivation:

The species is commonly planted for ornamental purposes and landscaping. It is planted for as live fencing and in agroforestry systems in strip and block plantations, using 4 × 4 m or 5 × 5 m spacing (or 1 × 1 m for fencing).

Productivity:

Culm production: Yuan (2010) reported 2500–3000 culms/ha.

Figure 2. *Bambusa multiplex*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath; e) Culm surface

4.3. *Bambusa polymorpha* Munro

Synonyms (Vorontsova et al., 2016):

Arundarbor polymorpha (Munro) Kuntze, *Bambusa cyanostachya* Kurz ex Gamble.

Common names (language/area in parentheses):

Hui gan zhu (China); *Jama betwa* (Assam-India)*; Faura* (Tripura-India); *Wakobor* (ADC Dukli, DebBarma-Tripura); *Kyanthung-wa* (Myanmar); *Pharua* (Sylhet, Bangladesh); *Mascumba, Burma, Rangoon bans* (Chittagong, Bangladesh*)*; *Pai Hom* (Thailand).

Description:

A densely tufted bamboo species with very short-necked pachymorph rhizomes. Culms are erect and attain a height of 10–25 m (Kumari and Singh, 2014; Banik, 2016) and a diameter of 5-15 cm (Banik 2016, Kumari and Singh 2014). Culms have a wall thickness of 1.5–2 mm. Lengths of internodes vary from 40 to 95 cm (Kumari and Singh, 2014; Banik, 2016). Branching in the species is from mid-culm upwards. Nodes are slightly prominent. Culm-sheaths are persistent, 20–25 cm long and 30-35 cm broad, broader at the base and rounded at the top, covered on back with densely and closely appressed brown to dark brown deciduous hairs; the ligule is narrow, irregularly dentate, and ciliate; the auricles are unequal, falcate, continuous with the sheath, and with deciduous bristles. The blade is 6–10 cm long and reflexed, deciduous, base triangular cordate, apex acuminate, abaxial surface with brown pubescence and adaxial surface felted with dark hairs, and margins ciliate. Young shoots are brownish-green with a light brown or sometimes greenish or golden yellow sheath, covered with dark brown hairs, blades greenish with dark brown hairs; lower half margin with whitish or yellowish cilia, boat shaped, at the tip of the shoot auricles biseriate, prominent, wavy, with whitish or yellowish cilia. Leaves are linear-lanceolate, 7–18 cm long and 1–2 cm broad(Figure-3).

Distribution:

A. Native range:

Bangladesh to China (Yunnan) and Indo-China

China: China South-Central

Bangladesh

Indo-China: Laos, Myanmar, Thailand

Malesia: Jawa, Myanmar, Thailand

B. In cultivation/naturalized in:

Indian Subcontinent: Assam, Eastern Himalaya, Sri Lanka)

Caribbean: Cuba, Puerto Rico

Western South America: Ecuador

In Kenya it is cultivated in Busia-Butula, private plot (AEZ-LM1)

Climatic parameters:

B. polymorpha grows within a temperature range of 3–35°C (Banik, 2016), but tolerates down to −3°C (Durai and Long, 2019) and up to 53°C (Durai and Long, 2019). The species grows well in areas with a precipitation of 3000–6000 mm (Banik, 2016) and elevations of 300–500 m (Kumari and Singh, 2014). In Kenya the species grows at 1227 m.a.s.l, mean annual rainfall 1600 mm and mean annual temp 22.2°C.

Soil:

B. polymorpha prefers deep, rich, well-drained, fertile loam soils (Banik, 2016). Soil organic content: soil pH. In Kenya it is found growing on Clay with sand.

Native habitat:

The species is found at the borders of mixed subtropical evergreen forests and prefers a moist, shady habitat (Kumari and Singh 2014). It is found particularly on lower slopes and in well-drained valleys, is often associated with Teak in moist mixed deciduous forests, and prefers tall trees (Banik, 2016). Also found associated with *Cephalostachyum pergracile* in moist soils.

Propagation:

The species has a flowering cycle of 35–60 years (Kumari and Singh, 2014). The seed weight (number in 1 g) is 0.038 and gives a germination of 40% (Dransfield and Widjaja, 1995). Clonal propagation is successful with seedling macro proliferation after six months of germination in nursery beds. Rhizome offsets from 2-year-old culms give 100% success (Dransfield and Widjaja, 1995; Benton, 2015). Culm cuttings are the best method for clonal propagation in this species (Banik, 2008), but branch cuttings give 90% success (Benton, 2015) and air layering 80% success (Benton, 2015; Durai and Long, 2019).

Cultivation:

Homestead plantation at a spacing of 4 × 4 m is adopted.

Productivity:

Culm production of 22 t ha^{-1} of air-dried culms in a 3-year rotation was reported.

Uses:

Traditional uses: construction, edible shoots, stick-based products, agricultural implements, and landscaping (Long and Durai, 2019). The potential is high for paper/pulp and engineered bamboo. The species is ideal for agroforestry systems and can serve as a windbreak and protection against soil erosion.

Figure 3. *Bambusa polymorpha*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath

4.4. *Bambusa spinosa* Roxb.

Subspecies/varieties/clones:

Bambusa blumeana Schult. f., *Bambusa blumeana* var. *luzonensis* Hack.

Synonyms (Vorontsova et al., 2016):

Arundo spinosa (Roxb.) Oken, *Ischurochloa spinosa* (Roxb.) Buse, *Arundarbor spinosa* (Roxb.) Kuntze, *Bambusa arundinacea* var. *spinosa* (Roxb.) E.G. Camus, *Bambusa bambos* var. *spinosa* (Roxb.) S.S. Jain & S. Biswas, *Bambusa spinosa* Blume ex Nees, *Bambusa blumeana* Schult.f., *Schizostachyum durie* Rupr., *Arundarbor blumeana* (Schult.f.) Kuntze, *Bambusa pungens* Blanco, *Arundarbor pungens* (Blanco) Kuntze, *Bambusa teba* Miq., *Arundarbor teba* (Miq.) Kuntze, *Bambusa stenostachya* Hack., *Ischurochloa stenostachya* (Hack.) Nakai, *Bambusa blumeana* var. *luzonensis* Hack.

Common names (Language/area in parentheses)

Spiny bamboo, Thorny bamboo (English); *Buluh duri, Buluh sikai* (Malaysia); *Anoo, Batakan, Baugin, Dugian, Baugin cana espina, Kauayan, Kauayan ng bayog, Kauayan totoo, Kauayan gid, Kauayan potog, Kabugauan, Kauyang siitan, Kawayang tinik, Lamnuan, Marurugi, Pasingan, Paua, rugian, Cana espina* (Philippines); *Tre gai*, *Tre lá ngắn* (Viet Nam); *Bamboo duri*, *Haur cucuk*, *Pring gesing* (Indonesia); *Russei rollick* (Cambodia); *Phaix ban*: *nz* (Lao PDR); *Phai see suk*, *Waa me bo* (Thailand); *Le zhu* (China).

Description:

A densely tufted erect bamboo with spiny branches and short-necked pachymorph rhizomes. Culms grow to a height of 15−25 m (Mohmod et al, 1993). The culm diameter is 7.3–8.7 cm (Mohmod et al, 1993); 7.8–10.3 cm (base), 8.13–9.65 cm (mid), 7.06–7.6 cm (top) (Salzer et al, 2018). Internodes are 18–60 cm long and wall thickness is 0.7–1.5 cm (Mohmod et al, 1993; Dransfield and Widjaja, 1995). Nodes are prominent (Dransfield and Widjaja, 1995). Branching starts from the base upward, forming a thick interlacing thicket (Figure-4).

Distribution:

A. Native range:

Jawa to Maluku

Malesia: Borneo, Jawa, Lesser Sunda Islands, Maluku, Philippines

B. In cultivation/naturalized in:

China: China South-Central, China Southeast

Indian Subcontinent: Bangladesh

Indo-China: Cambodia, Laos, Thailand, Viet Nam

Malesia: Malaysia

Caribbean: Puerto Rico

In Kenya it is cultivated in Kiambu- Muguga, experimental plot (AEZ- LH3) and Kilifi-Jilore, experimental plot in AEZ-CL4

Climatic parameters:

The species grows at 18-32°C but can tolerate 8-37°C. It prefers a mean annual rainfall of 1500-4000 mm, but tolerates 1000-5000 mm. It grows at elevations of up to 1000 m. In Kenya is found cultivated in location with temperature of 16-27 °C and at elevations from 25 to 2070 m.a.s.l. with means annual rain fall of 927 to 1059 mm.

Soil:

The species grows on heavy soils and on marginal land. The optimum pH is 5–6.5. It does not tolerate salinity (Dransfield and Widjaja, 1995). In Kenya the species is found growing well in Loamy and sandy soils.

Native habitat:

This species is native to mixed moist deciduous forest, but is no less common in mixed dry deciduous forest and semievergreen forest. It grows well along riverbanks, hill slopes, and freshwater creeks. The species tolerates flooding (Dransfield and Widjaja, 1995).

Propagation:

B. spinosa has a flowering cycle of 20–30 years; sporadic flowering is reported, but without any seed set (Dransfield and Widjaja, 1995). Clonal propagation is reported to be successful through 2–3 noded culm cuttings taken from the middle portion of 1–2-year-old culms and 3-noded cuttings from branches, up to 1.5 cm in diameter, from 1–2-year-old culms with hormone treatment (Dransfield and Widjaja, 1995). No reports are known of micropropagation procedures.

Cultivation:

Spacing of 8 × 8 m or 10 × 10 m is used for block plantations (Dransfield and Widjaja, 1995).

Productivity:

Culm production: 8 culms/year (800–1200/ha) in managed plantations, 5 culms/year (500–750/ha) in unmanaged plantations. 960–1600 culms/ha/year in natural stands have been reported by Dransfield and Widjaja (1995). Standing crop production (dry weight) is estimated at 143 t ha^{-1} (120 t for culms, 18 t for branches, 5 t for leaves) (Dransfield and Widjaja, 1995); 143 Mg (Uchimura, 1978); 9 t ha^{-1} y^{-1} of paper pulp (Dransfield and Widjaja, 1995).

Uses:

Traditional uses: weaving, construction, household implements, edible shoots (a preferred species), windbreaks, and live fences (Dransfield and Widjaja, 1995). Industrial uses: laminated bamboo, paper pulp, chopsticks, furniture, and flooring tiles (Dransfield and Widjaja, 1995; Tesoro and Espiloy, 1988). The potential is high for bioenergy, biorefinery, and engineered bamboo. The species is planted along riverbanks to control soil erosion. The species has been used for furniture made of round culms.

Figure 4. *Bambusa spinosa*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath; e) Thorny branches

4.5. *Bambusa tulda* Roxb.

Subspecies/varieties/clones:

Bambusa tulda Roxb. var. *tulda*, *Bambusa tulda Roxb.* var*. gamblei* P. Kumari & P. Singh var. *nov.*

Synonyms (Vorontsova et al., 2016):

Dendrocalamus tulda (Roxb.) Voigt, *Bambusa macala* Buch. Ham. ex Munro, *Bambusa trigyna* Roxb. ex Munro.

Common names (Language/Area in parentheses):

Jati bah (Assam-India); *Mitinga/Mirtenga* (Tripura-India, Bangladesh); *Taleda/Taral/Telda* (West Bengal, Odisha-India); *Raw thing* (Mizoram-India), *Thaik-wa* (Myanmar); *fu zhu* (China); Bengal bamboo, Calcutta cane, East India brown bamboo (English).

Description:

A medium-sized clumping bamboo with short-necked pachymorph rhizomes. The culms are erect and apically drooping; they attain a height of 8–30 m and are sometimes zigzagged at the lower part. Culm diameters are 5–10 cm and the wall thickness is 0.75–2.75 cm. Internode lengths are 18–35 cm. Branching occurs from the fourth node upward, and nodes are slightly prominent(Figure-5).

Distribution:

A. Native range:

Himalaya to China (Yunnan) and Indo-China
China: China South Central, China Tibet
Indian Subcontinent: Assam, Bangladesh, East Himalaya, India, Nepal, West Himalaya
Indo-China: Laos, Myanmar, Thailand, Viet Nam

B. In cultivation/naturalized in:

Western Asia: Iraq
Caribbean: Puerto Rico
Western South America: Columbia, Ecuador
Brazil: Brazil Southeast
In Kenya cultivated in Kiambu-Muguga, experimental plot (AEZ-LH3))

Climatic Parameters:

B. tulda grows well in moist and moderately high rainfall (4000–6500 mm) areas with temperature range from 4 to 37 °C and seen up to 1500 m altitude (Banik, 2016). In Kenya, grows at elevation of 2070 m.a.s.l, annual rainfall of 954 mm and mean annual temperature of 16°C.

Soil:

The species prefers fine-textured moist alluvial soil in good rainfall areas, such as semi-evergreen forests (Seethalakshmi and Muktesh Kumar, 1998; Nautiyal, Nautiyal and Chaukiyal, 2008; Singh et al, 2010) and flat alluvial deposits (Banik, 2016). In Kenya the species performs well in loamy soils.

Native habitat:

The species grows along the borders of evergreen forests and foothills in humid tropical and subtropical regions (Seethalakshmi and Muktesh Kumar, 1998; Anon, 2005; Nautiyal, Nautiyal and Chaukiyal, 2008; Singh et al, 2010). It is found in association with *Shorea robusta* (Sal) and in mixed deciduous forests.

Propagation:

The species shows both sporadic and gregarious flowering (Srivastava et al, 2012) and estimates of its flowering cycle vary between 15 and 40 years (Kumari and Singh, 2014; Benton, 2015). Seed weight (Number in 1 g) is estimated at 15 (Banik, 2000), 23.7 (Suraj and Nath, 2011), and 23.69 (Srivastava et al, 2012). Germination rates of 97% (Srivastava et al, 2012), 75% (Sarma et al, 2010), and 92% (Ahlawat et al, 2002) in 9–30 days have been reported. Viability under proper storage conditions is three months.

Clonal propagation through seedling macro proliferation is feasible in this species (Kumar, 1994). Rhizome offsets taken from 1–2-year-old culms (Singh et al, 2010) and culm cuttings from mid to lower nodes have been successfully used for propagation (Banik, 2008). Branch cuttings and air layering are also successful (Benton, 2015). Tissue culture propagation through axillary bud proliferation has been reported by Saxena and Bhojwani (1991) and Mishra et al (2008).

Cultivation:

Plantation type: Block plantations, agroforestry plantations at a spacing of 5 × 5 m. Mixing with trees like Teak, Shorea, and agroforestry species is feasible.

Productivity:

Culm production has been estimated at 1088 culms ha^{-1} (Majumdar, Choudhary and Datta (2016), 2016) and Above Ground Biomass (AGB) at 100.29 Mg ha^{-1} (Devi and Singh, 2021). The species shows tremendous variability, and 19 genotypes are recognized (Singh, 1993). Surveys, germplasm collections, and selections of superior genotypes for propagation have been undertaken by ICFRE, India, throughout the native habitats in India (Ginwal, 2021).

Uses:

Traditional uses: handicrafts, basketry, construction (Benton, 2015), edible shoots, incense sticks, furniture (Benton, 2015), mats, baskets, fishing rods, and flutes. Industrial uses: laminated bamboo (Benton, 2015), strand woven board (Mohmod et al, 1993), paper, and pulp (Tesero and Espiloy, 1988). In Kenya the species has been used for furniture making. Potential exists for bioenergy, biorefinery, and carbon trading. It is a common species in flood-prone areas of northeast India and is therefore important in soil erosion control. The species also comes up well in drier tracts and has the potential for eco-restoration.

Figure 5. *Bambusa tulda*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath

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

Subspecies/varieties/clones:

Three varieties: Green, Yellow ('Striata'), and Buddha Belly ('Wamin').

Synonyms (Vorontsova et al., 2016):

Leleba vulgaris Schrad. ex J.C.Wendl., *Arundo mitis* Lour., *Bambos mitis* (Lour.) Poir., *Bambusa mitis* (Lour.) Steud., *Phyllostachys mitis* (Lour.) Rivière & C.Rivière, *Arundarbor mitis* (Lour.) Kuntze, *Nastus thouarsii* Raspail, *Bambusa thouarsii* (Raspail) Kunth, *Nastus viviparus* Raspail, *Bambusa striata* Lodd. ex Lindl., *Arundarbor striata* (Lodd. ex Lindl.) Kuntze, *Bambusa vulgaris* var. *striata* (Lodd. ex Lindl.) Gamble, *Leleba vulgaris* var. *striata* (Lodd. ex Lindl.) Nakai, *Bambusa mitis* Blanco, *Bambusa monogyna* Blanco, *Arundarbor monogyna* (Blanco) Kuntze, *Bambusa humilis* Rchb. ex Rupr., *Bambusa surinamenis* Rupr., *Arundo fera* Oken, *Bambusa fera* (Oken) Miq., *Arundarbor fera* (Oken) Kuntze, *Bambusa blancoi* Steud., *Arundarbor blancoi* (Steud.) Kuntze, *Bambusa sieberi* Griseb., *Bambusa auriculata* Kurz, *Gigantochloa auriculata* (Kurz) Kurz. *Oxytenanthera auriculata* (Kurz) Prain, *Bambusa madagascariensis* Rivière & C.Rivière, *Bambusa vulgaris* var. *vittata* Rivière & C.Rivière, *Bambusa vulgaris* f. *vittata* (Rivière & C.Rivière) McClure, *Bambusa vulgaris* var. *latiflora* Balansa, *Bambusa latiflora* (Balansa) T.Q.Nguyen, *Bambusa nguyenii* Ohrnb., *Bambusa wamin* E.G. Camus, *Bambusa vulgaris* var. *aureovariegata* Beadle, *Bambusa vulgaris* f. *waminii* T.H.Wen.

Common names (Language/Area in parentheses):

Long tou zhu (China); *Jai borua* (Assam-India).

Description:

Large, tufted bamboo with short-necked pachymorph rhizomes. The loosely clumping, erect culms with drooping tips are slightly bent at the base. Culms are 8–15 m high and have a diameter of 5–9 cm and wall thickness of 7.3–15 mm. Internodes are deep green and length 20–30 cm long (Flora of China, 2006). Branching occurs from lower nodes upward, and nodes are slightly prominent. Culm sheaths are deciduous, apex arched below the blade, concave below the auricles; auricles conspicuous, ascending, nearly equal in shape and size, oblong or reniform, 8–10 mm; oral setae curved, fine; ligule 3–4 mm, serrate, very shortly white ciliolate; blade deciduous, erect or deflexed, broadly triangular to triangular, base slightly rounded, ca. 1/2 width of sheath apex, abaxially sparsely stiffly dull brown hairy, adaxially

densely stiffly dull brown hairy between veins, apex involute, sharply apiculate. Leaf blade narrowly lanceolate, 10–30 × 1.3–2.5 cm, both surfaces glabrous(Figure-6).

Distribution

A. Native range:

China: China South Central

Indo-China: Cambodia, Laos, Myanmar, Thailand, Viet Nam

B. In cultivation/naturalized in:

Northern Africa: Libya

West Tropical Africa: Benin, Burkina, Ghana, Guinea, Ivory Coast, Nigeria, Sierra Leone, Togo

West-Central Tropical Africa: Cameroon, Gulf of Guinea Islands. Rwanda, Zaire

Middle Atlantic Ocean: Ascension

Western Indian Ocean: Aldabra, Chagos Archipelago, Madagascar, Rodrigues

Indian Subcontinent: Assam, Bangladesh, Eastern Himalaya, India, Maldives, Sri Lanka

Indo-China: Andamans

Malesia: Jawa, Malaya, Maluku

Papuasia: Bismarck Archipelago, New Guinea

Southwestern Pacific: Tonga, Wallis and Futuna Islands

North Central Pacific: Hawaii

Southeastern U.S.A.: Florida, South Carolina

Mexico: Mexico Central, Mexico Northeast, Mexico Gulf, Mexico Southwest, Mexico Southeast

Central America: Costa Rica, El Salvador, Honduras, Nicaragua, Panama

Caribbean: Cayman Islands, Cuba, Dominican Republic, Haiti, Jamaica, Leeward Islands, Puerto Rico, Trinidad and Tobago, Windward Islands

Western South America: Colombia, Ecuador, Peru

Brazil: Brazil West Central, Brazil Northeast, Brazil Southeast, Brazil South

In Kenya it is a commonly cultivated species (reported in private farms at Migori-Kehancha (AEZ-LM2) and Muranga-Gatanga (AEZ-UM1) and in an experimental plot at Kiambu-Muguga (AEZ-LH3).

Climatic parameters:

B. vulgaris grows from sea level to 870 m altitude in areas with an annual rainfall of 1364.3-2585 mm and a temperature of 25°C. In Kenya the species is found at 1504 -2070 m.a.s.l. in locations with mean annual rainfall from 954-1800 mm and mean annual temperature of 16-22°C.

Soil:

This species is widely grown at a depth of 4.5-6 m on sandy, silty, hydromorphic, and sandy volcanic soils, vertisols and ferralitic soils, and andosols (Nfornkah et al, 2020). In Kenya it is commonly found on sandy clay and loams.

Native habitat:

The species is found on riversides in open forests in Yunnan (Flora of China, 2016).

Propagation:

B. vulgaris is a sterile species that rarely flowers and sets no seeds. Clonal propagation through culm and branch cuttings and pre-rooted rhizomes is the common means of propagation. Ground layering and air layering are also successful. Micropropagation through axillary bud proliferation has been achieved by Nadgir et al (1984), Arya and Arya (2009) and Ramanayake et al (2006).

Cultivation:

Spacing of 6 × 6 m, 8 × 8 m, or 12 × 12 m is used for block plantations.

Productivity:

Culm production: 10 t ha^{-1} y^{-1} (Seethalakshmi and Muktesh Kumar, 1998); 2296 culms/ha (Nfornkah et al, 2020). Above Ground Biomass: 29 kg (Nfornkah et al, 2020).

Uses:

Traditional uses: handicraft, weaving, construction, edible shoots. Industrial uses: particle board (Calegari et al, 2007; Gauss et al, 2019), laminated bamboo (Biswas et al, 2009), paper pulp, charcoal, engineered bamboo. The potential for biofuel and biorefinery feedstock is high. *B. vulgaris* is a truly pan-global bamboo species and has adapted well to a range of climatic conditions. It is tolerant of both drought and salinity and can therefore be used for ecorestoration programs with good success.

Figure 6. *Bambusa vulgaris*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath; e) *B. vulgaris* var *striata*

4.7. *Dendrocalamus asper* (Schult.f.) Backer ex Heyne

Subspecies/varieties/clones:

Dendrocalamus asper cv betung wulung, cv Tahi green and cv Phai Tong Dam (Benton, 2015); *D. asper* f. *niger* Hildebrand and Betung Hitam (Rao, Ramanatha Rao and Williams, 1998).

Synonyms (Vorontsova et al., 2016):

Arundo piscatoria Lour., *Calamagrostis piscatoria* (Lour.) Steud., *Bambusa aspera* Schult.f., *Arundo aspera* (Schult.f.) Oken, *Gigantochloa aspera* (Schult.f.) Kurz, *Sinocalamus flagellifer* T.Q.Nguyen, *Bambusa bitung* Schult.f., *Schizostachyum bitung* (Schult.f.) Steud., *Arundarbor bitung* (Schult.f.) Kuntze, Revis., *Bambusa flagellifera* Griff. ex Munro, Trans., *Dendrocalamus flagellifer* Munro, *Schizostachyum loriforme* Munro, *Dendrocalamus asper* f. *niger* Hildebr.

Common names:

Buong (Viet Nam)*, ma lai tian long zhu* (China).

Description:

Large, tufted, erect bamboo with short-necked pachymorph rhizomes. Culms reach 15–30 m high (Flora of China, 2006; Benton, 2015) and have a diameter of 6–20 cm (Flora of China, 2006; Benton, 2015) and wall thickness of 1.1–2 cm (Benton, 2015; Banik, 2016). Culms have an internode length of 30–50 cm (Flora of China, 2006; Benton, 2015), and branches form from the ninth node upwards (Flora of China, 2006) the culm (Figure-7).

Distribution:

A. Native range:

Bangladesh to China and Malesia

China: China South Central, China Southeast

Indian Subcontinent: Bangladesh

Indo-China: Andamans, Laos, Myanmar, Thailand, Viet Nam

Malesia: Borneo, Jawa, Lesser Sunda Islands, Malaya, Maluku, Philippines, Sulawesi, Sumatera

Papuasia: New Guinea

B. In cultivation/naturalized in:

Indian subcontinent: Sri Lanka

Papuasia: Bismarck Archipelago

Caribbean: Puerto Rico

Western South America: Colombia, Ecuador

Brazil: Brazil West-Central, Brazil Northeast, Brazil Southeast, Brazil North, Brazil South

In Kenya it is cultivated in Kiambu-Muguga in experimental plot (AEZ-LH3), Muranga-Gatanga (AEZ-LM1) and Busia (AEZ –UM1) in private farms.

Climatic parameters:

The species grows in areas with an average temperature of 27°C and annual precipitation of 217 mm at elevations of 600–1500 m. In Kenya it is grown in locations with elevations from 1227-2070 m.a.s.l. and with annual rainfall ranging from 954 mm to 1800 mm and mean annual temperature 16- 22°C

Soil:

This species will grow in any type of soil, although it grows better on heavy soils with good drainage. In Thailand, the species will grow well on sandy and rather acidic soils. In Kenya it is grown in locations with Loam and clay with sand.

Propagation:

Natural propagation occurs through seeds. 36.5% germination is obtained after 18 months of storage at 5°C (Banik, 2015). Clonal propagation through seedling macro proliferation is feasible in nurseries at intervals of six months. Rhizome offsets give a success rate of 70–80% (Banik, 1995). Micropropagation through axillary bud proliferation (Arya et al, 2002; Singh et al, 2011; Banerjee, Gantait and Pramanik, 2011) is successful and has been commercialized in India.

Cultivation:

Spacing of 5 × 5 m or 6 × 6 m is used for block plantations and plantations for edible shoots.

Productivity:

Culm production: 10–11 t ha^{-1} y^{-1} (Malanit, Barbu and Frühwald, 2009), 660–1070 kg ha^{-1} y^{-1} (air dried) from 3-4-year-old plantation (Tesoro and Espiloy, 1988). Above Ground Biomass has been estimated at 16 t culms/ha per year (Pungbun, 2000).

Uses:

Traditional uses: handicraft and construction. The species is much preferred for edible shoots. Industrial uses: laminated bamboo (Malanit, Barbu and Frühwald, 2009), oriented strand board (Febrianto et al, 2012; Malanit, Barbu and Frühwald, 2011, 2011) and parquet flooring (Tesoro and Espiloy, 1988). It has good potential for bioenergy production and biorefinery. As a species with good performance around the world, its use in ecorestoration programs is ideal because livelihood development is also possible. Its other advantages lie in its abilities to bind soil and form leaf-litter mulch. In Kenya it is used for round bamboo furniture.

Figure 7. *Dendrocalamus asper*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath; e) Culm surface

4.8. *Dendrocalamus brandisii* (Munro) Kurz

Synonyms (Vorontsova et al., 2016):

Bambusa brandisii Munro; *Arundarbor brandisii* (Munro) Kuntze.

Common names (Language/area in parenthesis):

Bulka, Wanan, Burma bamboo (India); Bo shi tian long zhu (China); Kyalo-wa, wabo (Myanmar); hôk (Lao PDR); phai-bongyai phai-sangyen (Thailand).

Description:

The species is a large, tall evergreen bamboo with erect culms and short-necked pachymorph rhizomes (Banik, 2016). Culms attain a height 19–33 m (Seethalakshmi and Muktesh Kumar, 1998; Flora of China, 2016). Culm diameter is 13–20 cm (Seethalakshmi and Muktesh Kumar, 1998), wall thickness 1.7–3 mm (Viswanath et al., 2007) and internode length, 30–43 cm (Seethalakshmi and Muktesh Kumar, 1998; Viswanath et al., 2007; Flora of China). Branching is mostly mid-culms upward and nodes are not prominent, but aerial roots are present(Figure-8).

Distribution

A. Native range:

China South-Central

B. In cultivation/naturalized in:

Indian Subcontinent: Bangladesh.

Indo-China: Andaman Islands, Laos, Myanmar, Thailand, Viet Nam.

In Kenya the species is cultivated in experimental plot in Kiambu-Muguga (AEZ-LH3)

Climatic parameters:

D. brandisii grows in wet tropics at elevations up to 1300 m.a.s.l. but in Kenya has been grown in areas with elevation of 2070 m.a.s.l and annual rainfall of 954 mm and mean annual temperature of 16°C

Soil:

In Myanmar, the species is frequently found on limestone, but it also grows well on well-drained. In Kenya the species is grown on loamy soils.

Propagation:

The flowering cycle in *D. brandisii* is 40–50 years and the seed weight is 100 seeds/gram (Viswanath et al., 2013). Germination of up to 90 % is obtained within 90 days of collection (Viswanath et al., 2013).

Seedling macroproliferation is feasible at six-month intervals. Clonal propagation through rhizome offsets and culm cutting, treated with hormones, are used routinely for propagation. (Somen et al.,2011). Rhizomatous branch cuttings have a success rate of 70 % (Somen et al., 2011). Tissue culture through axillary bud proliferation (Mukunthakumar et al., 1999; Chetan, 2012; Muralidharan and Seethalakshmi, 2017) and through somatic embryogenesis (Vongvijitra, 1988; Nadgauda et al., 1990; Zamora, 1994; Muralidharan and Seethalakshmi, 2017) has been reported.

Cultivation:

Planting in block plantations, and agroforestry is done at spacing of 5x5 m, 6x6 and 6x10 m (Viswanath et al., 2013). Intercropping with ginger can be practiced in agroforestry (Viswanath et al., 2007).

Productivity:

Annual fresh culms/clump: 2 (third year) to 10+ (eighth year) up to 40 Viswanath et al., 2007); Annual shoot production is 19.32−23.57 t/ha (Maoyi, 2007).

Uses:

Traditional use of the species is for handicraft, weaving, whole culms in construction. The species is very much preferred for edible shoots. Industrial uses are for laminated bamboo, strand woven board, paper pulp, composite fiber, edible shoots.

Figure 8. *Dendrocalamus brandisii*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath; e) Culm surface

4.9. *Dendrocalamus giganteus* Munro

Synonyms (Vorontsova et al., 2016):

Sinocalamus giganteus (Munro) Keng f., *Bambusa gigantea* Wall.

Common names (Language/Area in parentheses):

Giant bamboo (English); *Maipo, Bhalo bans, Mari bol, Sadiya kako* (India) (Haridasan and Tiwari, 2008); *Bambu sembilang* (Indonesia); *Buloh betong, Bambu sembilang* (Malaysia); *Wabo, Ban* (Myanmar); *Russey prey* (Cambodia); *Po'* (Laos); *Phai-po, Phai-pok* (Thailand); *M[aj]nh t[oo]ng to* (Viet Nam).

Description:

D. giganteus is among the largest of all bamboos. The species has short-necked pachymorph rhizomes and culms that reach heights of 24–30 m and diameters of 20–30 cm. The wall thickness is 2–3 cm and the internodal length is 35–45 cm (Sint, Hapla and Myint, 2008). The nodes are flat, with branching on upper nodes only(Figure-9).

Distribution:

A. Native range:

India (West Bengal) to China (Yunnan)

Indian Subcontinent: Assam, Eastern Himalayas, India

China: South Central China

Indo-China: Laos, Myanmar

B. In cultivation/naturalized in:

Indian Subcontinent: Bangladesh, Nepal, Sri Lanka

Western Indian Ocean: Mauritius, Madagascar, Seychelles

Eastern Asia: China

Indo-China: Cambodia, Thailand, Viet Nam)

Malesia: Jawa, Malaya, Sumatera

Caribbean: Puerto Rico, Trinidad and Tobago)

Western South America: Ecuador

In Kenya it is cultivated in Kiambu-Muguga in experimental plots (AEZ-LH3); in private farms in Muranga-Gatanga (AEZ –UM1) and Migori-Kehancha (AEZ-LM2).

Climatic parameters:

The species grows up to an altitude1200 m. It prefers locations with low hills and valleys having moisture and organic matter (Banik, 2016). In Kenya it is cultivated at elevations from 1504 – 2076 m.a.s.l. and in locations with annual rainfall between 954 mm and 1800 mm and temperature of 16-22° C.

Soil:

The species prefers rich alluvial soils (Banik, 2016). In Kenya the species is grown in Loam and sandy clay.

Propagation:

The species has a flowering cycle (gregarious) of 30–60 years (Dransfield and Widjaja, 1995; Kumari and Singh, 2014), but sporadic flowering or part flowering is common. The seed weight (number in 1 g) is 20 and 60–75%. germination is obtained in 3–7 days (Banik, 2016).

Seedling macro proliferation is feasible about six months after transplanting in nursery beds or containers. Rhizome offsets are successful but not very practical because of the large size of the culm and rhizomes. Culm cuttings have been used successfully (20–40%) to produce rooted plants in 60–70 days; the mid-culm nodes were found to be best, whereas branch cuttings give 60–70% rooting in 45–55 days (Banik, 2008). Tissue cultures through axillary bud proliferation (Ramanayake et al, 2008; Arya et al, 2006) and organogenesis (Ramanayake and Wanniarachchi, 2003) have been successfully reported.

Cultivation:

Plantation in block plantations with spacing of 10 × 10 m, sometimes mixed with Teak.

Productivity:

Dransfield and Widjaja (1995) reported 200 culms and 200 young shoots/ha per year.

Uses:

Traditional uses: handicrafts, culms for construction, wall, ceiling, and floorboards (flattened culms); edible shoots (edible portion about 33%, or 550 g), furniture, ornamental (landscaping), and water pipes. Culm sheaths are made into hats. Industrial uses: laminated bamboo and paper pulp. There is good potential for flooring tiles and disposable plates from the culm sheath.

Figure 9. *Dendrocalamus giganteus*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath; e) Culm surface

4.10. *Dendrocalamus hamiltonii* Nees & Arn. ex Munro

Subspecies/varieties/clones:

Dendrocalamus hamiltonii var. *edulis* Munro; *Dendrocalamus hamiltonii* var. *hamiltonii*.; *Dendrocalamus hamiltonii* var. *undulatus* Stapleton.

Synonyms (Vorontsova et al., 2016):

Sinocalamus hamiltonii (Nees & Arn. ex Munro) T.Q. Nguyen.

Common names (Language/Area in parentheses):

Kako, Fonay, Pecha, Taqma, Unep, Wanoke, Pao, Phulrua, Maggar (India); *Vupa, Yiza, Watsa, Duling, Apo Khoguo, Hepai, Chentsu, Aghakhaub, Ratho, Apibo, Muyipru, Remhuh, Luhg, Woa, Talua, Waeng, Hepai, Vongnyu* (Nagaland, India); *Tama, Choya bans* (Nepal); *Phai-nual-yai, Pai-hok* (North, Thailand); *Waa-klu* (Karen, Thailand); *Manh tong nua* (Viet Nam); *Ko hoe, Hôk* (Laos).

Description:

A large, evergreen bamboo with short-necked pachymorph rhizomes. Culms are erect but slightly zigzag in appearance, with drooping (pendulous) tops that attain a height of 12–24 m (Naithani, 2011). The wall thickness is 1.2–2 mm and the internodal length is 30–50 cm. Stout branches grow from the base (Naithani, 2011) of the culm(Figure-10).

Distribution:

A. Native range:

Nepal to China (Yunnan) and Indo-China

China: China: South Central China

Indian Subcontinent: Assam, Bangladesh, Eastern Himalayas, Nepal

Indo-China: Laos, Myanmar, Thailand, Viet Nam

B. In cultivation/naturalized in:

Indo-China: Cambodia

In Kenya it is cultivated in experimental plots in Kiambu-Muguga (AEZ-LH3) and in private farms in Busia (AEZ-LM1)

Climatic parameters:

The species grows in areas with annual mean temperature above 16°C with 900–2000 mm annual rainfall and about 70% annual mean relative humidity (Zhan et al, 2016). It is found at elevations of 300–2000 m (Das, 1990). In Kenya the species is cultivated in loamy and clayey soils with sand, at elevations from 1227 to 2070 m.a.s.l and annual rainfall between 954-1600 mm and mean annual temp between 16-22°C.

Native habitat:

The species is found in upland areas with moist fertile soil, especially in hilly, semi-evergreen to evergreen forests. It commonly occurs along banks of streams and in valleys, often forming dense thickets, in evergreen and moist forests (Banik, 2016). The species seems to be a light demander and is rarely seen under the tree canopy. It does not tolerate biotic interference (Banik, 2016).

Propagation:

The flowering cycle is reported to be 30–40 years (Kumari and Singh, 2014), and the seed weight (Number in 1 g) is 26.4 (Kumari and Singh, 2014). Germination of 80-85% seeds occur in 3–7 days. Viability only lasts for up to 25 days without proper storage.

Clonal propagation through seedling macro proliferation is feasible (Kumari and Singh, 2014). Rhizome offsets are 60–70% successful for propagation (Banik, 2016). Culm cuttings (70–80%) and branch cuttings (70–75%) give good results, as do pre-rooted and pre-rhizomed branches from 1½–2-year-old culms (Banik, 2008; Banik, 2016). Propagation has been demonstrated through axillary bud proliferation (Arya, Kaur and Arya, 2012; Sood et al, 2002; Agnihotri and Nandi, 2009) and somatic embryogenesis (Godbole et al, 2002).

Cultivation:

The species is suitable for block planting and riverside planting. A spacing of 4 × 4 m (Banik, 2016) is ideal. Intercropping with Turmeric has been successful (Banik, 2016). The species takes 3–5 years to mature when established from rhizomes.

Productivity:

Above Ground Biomass (AGB) of 71.76 Kg/Clump has been reported by Alemeyhu et al (2015).

Uses:

Traditional uses: handicrafts, culm for construction, incense sticks, and as a preferred species for edible shoots (Banik, 2008), windbreaks in tea plantations (Naithani, 2011), pickled leaves (Pal, 1984), and fodder. Industrial uses: paper pulp (Naithani, 2011; Zhan et al, 2016). It has the potential for bioenergy, biorefinery, and engineered bamboo. The species plays an important role in its natural habitat as a source of food for wild animals. It is adapted to hilly slopes and can play a role in stabilizing soil and preventing landslips.

Figure 10. *Dendrocalamus hamiltonii*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath; e) Culm surface

4.11. *Dendrocalamus membranaceus* Munro

Synonyms (Vorontsova et al., 2016):

Bambusa membranacea (Munro) Stapleton & N.H. Xia, *Dendrocalamus longifimbriatus* Gamble, *Sinocalamus longifimbriatus* (Gamble) T. Q. Nguyen, *Oxytenanthera lacei* Gamble, *Dendrocalamus membranaceus* f. *fimbriligulatus* Hsueh & D.Z.Li, *Dendrocalamus membranaceus* f. *pilosus* Hsueh & D.Z.Li, *Dendrocalamus membranaceus* f. *striatus* Hsueh & D.Z.Li.

Description:

A large, evergreen clumping bamboo with short-necked pachymorph rhizomes and culms that reach a height of 8–25 m (Flora of China, 2006; Durai and Long, 2019). The culm diameter is 7–12 cm and the internode length is 34–42 cm (Flora of China, 2006; Durai and Long, 2019). Branching occurs from base to top, and the nodes are not prominent (Flora of China, 2006). Culm sheaths are deciduous, initially orange-green, elliptical to oblong, usually longer than the internodes, papery, margins ciliate; auricles are small; oral setae are short; the ligule is 8–10 mm, serrulate; and the blade is reflexed, linear-lanceolate, 30–40 × 2–3 cm. Leaf sheaths are initially sparsely hairy, becoming glabrous; the ligule is short, serrulate; and the blade is lanceolate, 12.5–25 × 1.2–2 cm(Figure-11).

Distribution:

A. Native range:

Bangladesh to China (S. Yunnan) and Indo-China

China: China South Central

Indian Subcontinent: Bangladesh

Indo-China: Cambodia, Laos, Myanmar, Thailand, Viet Nam)

B. In cultivation/naturalized in:

Malesia: Sumatera

Caribbean: Puerto Rico

Indian Subcontinent: Peninsular India

In Kenya it is cultivated in Kilifi-Gede (AEZ-CL4) and in experimental plots in Kiambu-Muguga (AEZ-LH3).

Climatic parameters:

D. membranaceus is found growing in the temperature range of 22–33°C (Durai and Long, 2019) in areas with precipitation of 1000 mm (Durai and Long, 2019). The preferred altitude for the species is 1150 m, but it is found growing from 50–1400 m (Durai and Long, 2019). In Kenya the species is cultivated in the low 25-85 m.a.s.l. as well as high elevations (2070 m.a.s.l.) in locations with annual rainfall ranging from 927 to 1059 mm and mean annual temperature from 16-27°C

Soil:

The species prefers a moist laterite or black limestone soil, but plants can tolerate arid and barren conditions (Seethalakshmi and Muktesh Kumar, 1998. It grows in light (sandy), medium (loamy), and heavy (clay) soils, preferring well-drained soil but can grow in nutritionally poor soil with mildly acid, neutral, and basic (mildly alkaline) pH values. In Kenya the species is cultivated in sandy and loamy soils.

Native habitat:

The species is found in river valleys, in hilly forested areas (Flora of China, 2006), or in mixed deciduous or monsoon forests (Durai and Long, 2019) as pure bamboo forest or mixed with broad-leaved trees in China.

Propagation:

The flowering cycle is 19–20 years, and germination of 38% is obtained (Seethalakshmi and Muktesh Kumar, 2002). Rhizome offsets, as well as culm and branch cuttings, are reported to be successful (Durai and Long, 2019). Micropropagation through axillary bud proliferation has been reported by Arya et al (2002).

Cultivation:

In agroforestry block plantations, spacing of 5 × 5 m is adopted.

Productivity:

A total of 6250 culms/ha has been reported by Komiya et al (2001) and an Above Ground Biomass (AGB) of 21.3 Mg ha^{-1} was reported by Yuen, Fung and Ziegler (2017).

Uses:

Traditional uses: construction (Yang et al, 2012; Durai and Long, 2019), edible shoots (Yang et al, 2012; Durai and Long, 2019), furniture (Yang et al, 2012). Industrial uses: laminated bamboo (Durai and Long, 2019), paper pulp (Yang et al, 2012; Durai and Long, 2019), fiber board, and chopsticks. The potential is high for bioenergy plantations and biorefinery.

Figure 11. *Dendrocalamus membranaceus*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath; e) Culm surface

4.12. *Dendrocalamus strictus* (Roxb.) Nees

Synonyms (Vorontsova et al., 2016):

Bambos stricta Roxb., *Nastus strictus* (Roxb.) Sm., *Bambusa stricta* (Roxb.) Roxb., *Bambusa tanaea* Buch.-Ham. ex Wall., *Bambusa pubescens* Lodd. ex Lindl., *Arundo hexandra* Roxb. ex Munro, *Bambusa glomerata* Royle ex Munro, *Bambusa hexandra* Roxb. ex Munro, *Bambusa verticillata* Rottler ex Munro, *Bambusa stricta* var. *argentea* Rivière, *Dendrocalamus strictus* var. *prainianus* Gamble, *Dendrocalamus prainiana* Varmah & Bahadur.

Common names (Language/Area in parentheses):

Latare, Katli, Lathi, Dominee, Salia bauns, Tursing, Karka, Nakur bans, Kiri bidiru, Narvel, Kalmungil, Kallumula, Sadanapa Veduru, Karali, Lathi bans, Karail (India); *Lathi* (Nepal); *Hmyin-wa* (Myanmar); *Bambu batu* (Indonesia) (Banik, 2016); *Kirok*, *Oham Nget*, *Tephrie rie* (Nagaland) (Naithani, 2011).

Subspecies/varieties/clones:

Three ecotypes, common, large, and *Karka*, are found in India. The common ecotype is medium-sized and has dense clumps with solid culms. The large ecotype (*Dominee bans* in Bihar and *Nadugani* form in Kerala) has loose clumps; its straight culms have smooth internodes. *Karka* is a dwarf ecotype found in Madhya Pradesh.

Description:

Dendrocalamus strictus is a densely tufted, deciduous sympodial bamboo with short-necked pachymorph rhizomes. The culms grow to a height of 6–15 m (Naithani, 2011) and in some areas up to 20 m (Benton, 2015). It attains a culm diameter of 2.5 to 7 cm (Naithani, 2011). The most common ecotypes have solid culms. Internode lengths are 30–40 cm, with the fifth-to-sixth internode being the longest (Naithani, 2011). Culms are slightly zigzag at times, nodes are slightly prominent, and branching is seen from base to mid-culm(Figure-12).

Culm sheaths are deciduous, orange-brown, about 3/4 as long as the internodes, thickly papery, margins ciliate, apex rounded; auricles are absent; the ligule is 1–3 mm, serrulate; the blade is erect, narrowly triangular. Leaf sheaths are initially sparsely hairy, becoming glabrous; the ligule is short, serrulate; the blade is usually narrowly lanceolate, 5–30 × 1–3 cm.

Distribution:

A. Native range:

Indian Subcontinent: Assam, India, Nepal, Pakistan, West Himalaya

Indo-China: Andamans, Laos, Myanmar, Thailand, Viet Nam

B. In cultivation/naturalized in:

West tropical Africa: Togo

Western Indian Ocean: Madagascar, Seychelles

China: China Southeast

Malesia: Jawa, Malaya

Southwestern Pacific: New Caledonia

Central America: Honduras

Caribbean: Bahamas, Cuba, Puerto Rico, Trinidad and Tobago, Windward Islands

Brazil: Brazil Southeast

In Kenya it is cultivation in experimental plot at Kilifi-Jilore (AEZ-CL4) and in priovate farmland in Migori-Kehancha (AEZ-LM2)

Climatic parameters:

The optimum mean temperature for the species is 20–30°C, but it can withstand extremes as low as −5°C and as high as 45°C (Banik, 2016). Mature plants are frost hardy, but young and tender culms are affected. The optimum annual rainfall is 1000–3000 mm, with 300 mm per month during the growing season. The species can also tolerate abnormal drought conditions (Banik, 2016).

Soil:

The species prefers well-drained soil, sandy loams, and hilly ground. It grows on loamy sand in Punjab, India (Singh et al, 2018) with reported soil pH values of 5.5–7.5 (Banik, 2016), 8.2–8.4 (Singh et al, 2018), and (under cultivation in Thrissur, Kerala, India) 5.8–6.1 (Kittur et al, 2016). It is cultivated in Kenya in sandy and sandy clay soils at low and medium elevations (25 to 1504 m.a.s.l) at locations with annual rainfall of 927 -1400 mm and mean annual temp 22-27°C

Native habitat:

D. strictus is common in dry deciduous forests and areas with low rainfall in many parts of India, Myanmar, and Thailand. The ecotype with tall, erect, hollow culms (*Dominee bans* in

Bihar and *Nadugani form* in Kerala) is found in moist areas. *Karka*, a dwarf type, is found in Madhya Pradesh, India. The species is associated with Teak in many locations in India.

Propagation:

The species flowers gregariously with an estimated 25–45-year cycle (Kumari and Singh, 2014), but sporadic flowering is more common. Seed weight is 51.5 seeds to 1 g (Kumari and Singh, 2014). Under normal storage, seed viability lasts only 30–35 days after collection (Banik, 2016), but 59% germination was obtained after 34 months of storing at 3–5°C after reduction of its moisture content to 8% (Varmah and Bahadur, 1980).

Clonal propagation is possible through seedling macro proliferation (Banik, 1987), rhizome offsets, culm cuttings, branch cuttings, and air layering (Banik, 1995; Benton, 2015). Tissue culture propagation has been reported through axillary bud proliferation (Chaturvedi, Sharma and Sharma, 1993; Ravikumar et al, 1998) and somatic embryogenesis (Saxena and Dhawan, 1999; Reddy, 2006).

Surveys, collections of germplasm accessions, and selections of superior genotypes have been carried out by ICFRE, India (Ginwal, 2021). The tall, hollow ecotype from moist areas has not been popular in plantations.

Cultivation:

Block plantations with spacings of 4 × 4, 3 × 4 m (Long and Durai, 2019), 1 × 1 m, 1.8 × 1.8 m, and 3 × 3 m (Patil, Mutanal and Shahapurmath, 2008) have been established. Interplanting leguminous crops, turmeric, ginger, and vegetables for the first three years is feasible. Dev et al (2020) found that intercrops with Sesame and Chickpea gave better culm yield at 10 × 12 m and 10 × 10 m respectively. The shooting season is from May to September, and shoots take two years to mature.

Productivity:

Singh et al (2004) reported an annual Above Ground Biomass of 91.35–103.70 Mg ha^{-1}.

Uses:

Traditional uses: handicrafts, construction, household implements, tool handles, ladders, fencing and partitions, walking sticks, and batons. Industrial uses: paper pulp and charcoal.

The potential for bioenergy, biorefinery, and ecorestoration is high in low rainfall areas. It is used for weaving baskets in Kenya.

Figure 12. *Dendrocalamus strictus*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath; e) Culm surface

4.13. *Phyllostachys aurea* (André) Rivière & C. Rivière

Subspecies/varieties/clones:

Phyllostachys bambusoides var*. aurea* (André) Makino, *Phyllostachys reticulata* var*. aurea* (André) Makino, *Sinarundinaria reticulata* var*. aurea (*André)*, Phyllostachys meyeri* var*. aurea* (André) Pilip., *Phyllostachys puberula* var*. flavescensinversa* J.Houz., *Phyllostachys aurea* var*. flavescensinversa* (J.Houz.) Nakai, *Phyllostachys aurea f. flavescensinversa* (J.Houz.) Muroi, *Phyllostachys bambusoides f. alternatolutescens I.Tsuboi*, *Phyllostachys reticulata f. alternatolutescens* (I.Tsuboi), *Phyllostachys aurea f. alternatolutescens (I.Tsuboi) Makino & Nemoto*, *Phyllostachys bambusoides f. albovariegata* Makino, *Phyllostachys reticulata f. albovariegata (*Makino) Makino & Nemoto*, Phyllostachys aurea f. albovariegata* (Makino).

Synonyms (Vorontsova et al., 2016):

Bambos koteisik Siebold*.; Bambusa koteisik* Zoll*.; Bambusa aurea* André*; Phyllostachys takemurae* Muroi in J. Sugimoto*; Phyllostachys breviligula* W.T.Lin & Z.M.Wu*; Phyllostachys formosana* Hayata.

Common names (Language/area in parentheses):

Golden bamboo, Fish-pole bamboo, Stick bamboo, Yellow bamboo, Castillon bamboo, Hardy timber bamboo, *Madake*, Giant timber bamboo, Japanese timber bamboo; Fairyland bamboo (Australia); Monk's belly bamboo (English); *Hotei-chiku*; *Pring uncue* (Indonesia).

Description:

A loosely clumping bamboo with long-necked leptomorph rhizomes. The culms attain a height of 2.5–12 m and a diameter of 1.0–5 cm, with a wall thickness of 2–8 mm. The internodes are 8–20 cm long, sulcate, with branches that are borne at the middle of the culm with unequal thickness. Nodes are prominent, with a white powdery wax below, and the lower ones are often irregularly short and swollen, while the upper ones are distal and horizontal. Branches occur in uneven pairs with sulcus. The stems and branches of *P. aurea* are green when they are young and turn golden yellow at maturity(Figure-13).

Culm sheaths are yellow-green or pale red-brown, becoming straw-colored, with variably sized brown spots, base edged with white pubescence; auricles and oral setae are absent; the ligule is yellow-green, truncate, or weakly convex at the apex, very short (1–2 mm), margin longer, pale green, and ciliate; the blade is reflexed, green, with yellow margins, linear, and flat or crinkled in upper sheaths.

There are some cultivars of *P. aurea*, such as *P. aurea* 'Flavescens Inversa' (lower culms with a pale yellow stripe on the sulcus), *P. aurea* 'Holochrysa' with the common name "golden golden" (culms turn yellow/gold sooner than the type form and random leaves have a yellow stripe), *P. aurea* 'Koi' (culms turn yellow, but sulcus stays green and random leaves have a yellow stripe), and *P. aurea* 'Takemurai' (culms grow taller and lack the compressed internodes of the type form).

Distribution:

A. Native range:

China (Fujian, Zhejiang) to Vietnam

China: China Southeast

Indo-China: Viet Nam

B. In cultivation/naturalized in:

Southwestern Europe: Spain

West-Central Tropical Africa: Cameroon

Caucasus: Transcaucasus

Indian Subcontinent: East Himalaya

Malesia: Jawa, Lesser Sunda Islands, Sumatera

Australia: New South Wales, Queensland, South Australia

New Zealand: Kermadec Islands, New Zealand North

Northwestern U.S.A.: Oregon

Southwestern U.S.A.: California

South-Central U.S.A.: Texas

Southeastern U.S.A.: Alabama, Arkansas, Florida, Georgia, Louisiana, Maryland, Mississippi, North Carolina, South Carolina, Tennessee, Virginia

Mexico: Mexico Central, Mexico Northeast

Central America: Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua

Western South America: Bolivia, Colombia, Ecuador, Peru

Brazil: Brazil West-Central, Brazil Southeast, Brazil South

In Kenya it is cultivated in private farms in Muranga-Gatanga (AEZ-UM1)

Climatic parameters:

P. aurea tolerates a wide range of temperatures of −15–26°C and sometimes as low as −20°C (Rickel and Rojas-Sandoval, 2017). This species grows at elevations of 700–2000 m with

annual precipitation of 1000 mm (Rickel and Rojas-Sandoval, 2017). In Kenya it is cultivated at elevation of 2056 m.a.s.l with mean annual rainfall 1600-1800mm, mean annual temperature of 18-19 °C.

Soil:

Sandy soils with drainage and rich nutrients are optimum for the wild growth of this species. *P. aurea* cannot withstand waterlogged conditions (Rickel and Rojas-Sandoval, 2017). In Kenya the species is grown in loamy soils.

Native habitat:

The species grows along stream edges in riparian corridors (Rickel and Rojas-Sandoval, 2017).

Propagation:

No seed setting has been reported in the species. Clonal propagation is undertaken through rhizome offsets. Clump parts, 0.5–1.0 m long and with a rhizome and roots, are also commonly used for large-scale planting with 100% success (Roxas, 2012). Tissue culture propagation through somatic embryogenesis has been found to be successful with this species (Huang and Huang, 1993). This species has been reported as invasive in many countries (Rickel and Rojas-Sandoval, 2017).

Uses:

Traditional uses: handicrafts, weaving, bamboo pipes, walking sticks, and umbrella and fan handles. It is a popular garden ornamental and hedge plant. Industrial uses: charcoal, briquettes, and pellets for bioenergy. There is potential for cultivation in degraded lands for restoration and carbon sequestration. In Kenya, the species is a popular ornamental plant.

Figure 13. *Phyllostachys aurea*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath

4.14. *Thyrsostachys siamensis* Gamble

Synonyms (Vorontsova et al., 2016):

Arundinaria siamensis Kurz, *Arundarbor regia* (Thomson ex Munro) Kuntze, *Bambusa siamensis* Kurz ex Munro, *Thyrsostachys regia* (Thomson ex Munro) Bennet, *Bambusa regia* (Munro, 1868).

Common names: (Language/Area in parentheses):

Pai ruak (Thai); Monastery bamboo, Umbrella-handled bamboo, Thai bamboo (English); *Shamu dake* (Japanese); *Bambu jepang, Bambu payung* (Indonesian); *Tam vong* (Vietnam); *Tiyowa, Kyaung-wa* (Myanmar).

Description:

A tightly clustered bamboo with short-necked pachymorph rhizomes. The culms attain a height of 8–16 m (Narasimhamurthy et al., 2013) and are mostly erect or gently arching with weeping tops. The diameter of the adult culm is 3–8 cm (Benton et al, 2011), with an average of 3.51 cm (Sompoh et al, 2013). The culms are solid at the base but with average wall thickness 8.89 mm at the top (Sompoh et al, 2013). The internodes of the species are 15–38 cm long (Benton et al., 2011; Narasimhamurthy et al., 2013), mostly protected with persistent old culm sheaths. Branches grow from mid-culm nodes upwards with a dominant primary branch of 17–87 cm (Roxas, 2012) and several smaller branches without spines. Nodes have a permanent sheath scar but are free of aerial roots and nodal ridges(Figure-14).

Distribution:

A. Native range:

China (S. Yunnan) to Indo-China

China: China South Central

Indo-China: Laos, Myanmar, Thailand, Viet Nam

B. In cultivation/naturalized in:

Indian Subcontinent: Bangladesh, Sri Lanka

Malesia: Malaya

In Kenya it is cultivated in the experimental plot in Kilifi-Gede, Jilore (AEZ-CL4).

Climatic parameters:

This species prefers an altitude of 300–1000 m with annual precipitation of 1000–2000 mm and a temperature of 20–30°C. In Kenya it is cultivated in locations at elevations between 25-85 m.a.s.l and with annual rainfall 927 -1059 mm and mean annual temperature of 27 °C

Soil:

T. siamensis grows well in a wide range of soils, especially sandy to clay loams, provided they are not waterlogged. In Kenya, it is cultivated in sandy soils,

Native habitat:

This species grows abundantly in open plains, slopes, and valleys and under the canopy in dry, mixed deciduous or semi-evergreen forests.

Propagation:

Sporadic and gregarious flowering cycles have been reported in this species. The number of seeds per gram varies widely from 10–82 and so is the germination potential which varies from 7–86%, with the bigger seeds germinating better (Banik, 2016).

Clonal propagation with rhizomes of one-year-old culms has been found to be very successful in this species (Banik 2016). Culm cuttings with 2–3 nodal buds and branch cuttings with hormone treatment were reported as successful by Banik (2016). Propagation through tissue culture was also reported to be successful through axillary bud proliferation (Banik, Islam and Hadiuzzaman (1993), as was somatic embryogenesis (Obsuwan, Duangmanee and Thepsithar, 2019).

Cultivation:

The species is ideal for closely spaced strip plantations along roadsides in 2–3 rows (Banik, 2016), and a spacing of 4 × 4 m is suitable for block plantations (Benton et al, 2011). Intercropping with timber trees, such as Teak, is also promising (Dransfield and Widjaja, 1995).

Productivity:

An average of 28 culms per clump were obtained from a seed-raised three-year-old plantation (Dransfield and Widjaja, 1995) and Scurlock, Dayton and Hames (2000) reported a production

of 1500 culms/ha. Production rates of 11–54 t ha^{-1} (Scurlock, Dayton and Hames, 2000) and 26.98 (culm) t ha^{-1} (Chaiyo, Garivait and Wanthongchai, 2011) have been reported.

Uses:

Traditional uses of the species are for handicrafts, construction, baskets, chopsticks, umbrella and broom handles, fishing rods, ornamental plants and windbreaks. It is a preferred species for edible shoots. Industrial uses include manufacture of laminates, paper pulp, charcoal, and fuel. In Kenya the species is used as props.

Figure 14. *Thyrsostachys siamensis*: a) Clump habit; b) Culms and branches; c) New shoot; d) Culm sheath

5. Identification of bamboos based on vegetative morphological characteristics

Identification of bamboo species in the field and in nurseries is generally considered difficult because of the limitations imposed by the lack of reproductive structures for most of their lifecycles. The taxonomy of grasses relies greatly on flowers, so bamboos, mostly not in flower, have largely been ignored by botanical collectors. Preparation of herbarium specimens is also difficult due to the large size of the culm, culm sheath, and inflorescence. Therefore, the identification of bamboo species in the field often has to be based on the morphology of the culm and the sheath. Field identification is further compounded by the rapid dehiscence, in many species, of the culm sheaths, which are of taxonomic importance. Many of the characteristics vary with the age of the culm and its sheath, from the bottom of the culm to the top.

Additional information, such as the natural habitat of native species and the history of introduction of exotic species, is useful in narrowing down the list to those likely to be present in the particular region. The morphological key to the identification of the bamboos of Kenya, given below, is based on morphological variations observed in the introductions of exotic bamboo species into the country and may therefore not be suitable for identification in other regions, where additional species might be present. For a wider set of species, the reader is advised to refer to the taxonomic keys available in the literature.

It should also be noted that intraspecies variation within each species is particularly significant, as is the proclivity to show variation when grown under different climatic conditions. Variations in culm diameter and color are commonly influenced by the prevailing conditions at the site.

5.1. Morphological characteristics of taxonomic importance

Traditionally, reproductive structures have played an important role in plant taxonomy, and description of the flower parts is considered essential to describe a new species. Because bamboos are perennials with long lifecycles and are mostly semelparous (having a single lifetime flowering event), the difficulty commonly encountered in identifying bamboo species in the field is the dependence on vegetative characteristics. The most important vegetative features are listed below.

- Culm sheath: The shapes of various parts of the culm sheath are very useful for species identification. The features to be noted are the ligule, auricle, and blade. The persistence of the sheath on the culm and the nature of appendages, such as hairs and cilia, are useful to characterize the species.
- The emerging shoot: The morphology and color of the new shoot as it elongates to its final size are characteristics of the species.
- The nodal region on the culm: This also offers several features of taxonomic importance, such as the presence of rings of hair above or below and the presence or absence of a prominent nodal ridge.
- The nature of the rhizome: The type (leptomorph or pachymorph) and length of the rhizome neck are distinguishing features.
- The surface of the culm: The presence or absence of hairs or of a waxy bloom are characteristics of the species, as is the color.

The culm node in bamboo is characterized by the presence of a scar at the point of attachment of the culm sheath. A supranodal ridge (a nodal ridge above the sheath scar) may be prominent in some species. Culm sheaths are found on new culms and either fall off as the culms elongate or remain in place, but degrade gradually over months. The size and shape of the parts of the culm sheath are important taxonomic features. The ear-like auricles on the two sides at the point of attachment of the blade and the shape and position of the blade with respect to the sheath body (erect, reflexed, or pendulous) are also important. The color and texture of the culm surface, especially of young culms, are often characteristic of the species. A waxy bloom, downy hairs, or smooth surfaces are easily observed features that help identify the species. Branches are alternately arranged in culms, and the number of branches is of taxonomic significance.

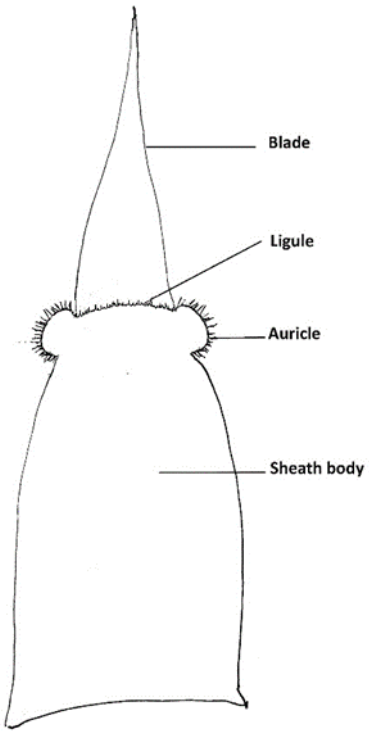

Figure 15. Parts of the culm sheath

5.2. Morphological identification keys for the bamboos of Kenya

1.

A. Rhizome leptomorph (thinner than culm diameter and running horizontally). Culms solitary or in clusters separated from each other ····· *Phyllostachys aurea*

B. Rhizome pachymorph (thicker than culms). Culms clumping together loosely or tightly ····· **2**

2.

A. Culms with spiny branches ····· **3**

B. Culms without spiny branches ····· **4**

3.

A. With white ring above node ····· *Bambusa bambos*

B. Without white ring above node ····· *Bambusa spinosa (B. blumeana)*

4.

A. Culms with persistent sheaths, densely clustered ····· *Thyrsostachys siamensis*

B. Culms without persistent sheaths ····· **5**

5.

A. Young culms with white waxy bloom ····· **6**

B. Young culms without bloom **7**

6.

A. Large-diameter hollow culms. Culm sheath 40–45 cm long and 50–55 cm wide at base, ligule serrate in the middle ..... *Dendrocalamus giganteus*

B. Medium to small diameter culms **8**

7.

A. Small diameter culms with rough, bright green surface, small leaves; culm sheath auricles very small or inconspicuous ..... *Bambusa multiplex*

B. Medium to large size culms **9**

8.

A. Culms solid at lower and middle internodes, sheath blade erect ..... *Dendrocalamus strictus*

B. Culms hollow, culm blade reflexed ..... *Dendrocalamus membranaceus*

9.

A. Prominent white ring above and below node ..... *Dendrocalamus hamiltonii*

B. White rings not present above node **10**

10.

A. Brownish-grey tomentose culms (lower nodes with rootlets, large leaves) ..... *Dendrocalamus asper*

B. Culm with smooth surface, green or yellow striped with green **11**

11.

A. Culm sheath auricles unequal **12**

B. Culm sheath auricles equal, 0.8–1 cm, sheath with stiff, dark brown hairs; leaf blade abaxially glabrous, blade apex involute (rolled) and with acuminate tip ..... *Bambusa vulgaris*

12.

A. Culm sheath cup-shaped; blades reflexed; culm sheaths with pale brown or white silky hairs ..... *Bambusa polymorpha*

B. Enlarged blades and large unequal auricles; culm sheaths broadly triangular, length less than 1/2 basal width, apex very broadly arched-convex or subtruncate; auricles ± horizontal ..... *Bambusa tulda*

6. Matching bamboo species with AEZs

Bamboos, as a group, are unique in their ability to adapt to a wide range of climatic and soil conditions. Other than regions with extremes of temperature and moisture, bamboo can survive, contribute to establishing green cover, and improve the soil. To maximize productivity and bring optimum returns to bamboo cultivators, it is essential that the choice of species is based on their growth performance under specific conditions and matched to the site.

The most important of the climatic factors that influence the survival and growth of bamboo is the temperature range, which is in turn influenced by the latitude and altitude of the location. Productivity is greatly influenced by the availability of moisture. In many of the sites visited, the bamboo clumps' growth was affected by a lack of management, which had resulted in congestion and a decline in culm quantity and quality.

Plantations of bamboo are established with commercial or environmental objectives. Productivity and quality of bamboo culms in terms of length, diameter, straightness, and wall thickness are of prime concern, both from the point of view of better economic returns to the grower and of quality raw material for industries. Commercial plantations would therefore be considered in situations where scientific management of the clumps is feasible to varying degrees to ensure survival and optimum productivity. Competing land uses would result in marginal or degraded sites being preferred for planting, necessitating management interventions that would include soil working, irrigation, mulching, and fertilization.

In the absence of well laid out field trials of bamboo species, decision making on appropriate species is limited to the observations made in species trials where the sample size is small and microclimatic conditions are not representative of the AEZ. Information from the literature on the performance of the species in similar climatic areas in other countries is the next best guide to decision making. An allowance for improved growth performance under a better management regime is considered when the suitability of different species is recommended. It should also be remembered that, because the choice of exotic bamboo species introduced to Kenya was not based on any systematic criteria, several other species with potential are missing. Future plantation programs will benefit from species trials with a broader set of bamboo species, whose choice will be based on similarities in climatic parameters. The recent INBAR publication, *Global Priority Species of Economically Important Bamboo* (Muralidharan and Sankar, 2023), is a useful guide to the selection of promising species because it takes the potential for commercial exploitation into consideration.

The recommendations for the suitability of bamboo species in various AEZs, listed below, are based on firsthand observation of the bamboo species during field visits to different sites in Kenya and other countries and from information available in the literature, notably INBAR's *A Bamboo Site–Species Matching Study in Kenya* (John et al, 2022).

Table 3. The recommendations for the suitability of bamboo species in various AEZs

Bamboo species	AEZ for which the species is suitable
Bambusa bambos	Most suitable for Zones CL2–4 and LM1–2 but also UM1–2 and LH3 up to 1600 m.a.s.l. Regular pruning of thorny branches is essential to keep clumps in healthy condition.
Bambusa multiplex	The species is suitable in both lower and higher elevations. Suitable for LM1–3 and UM1–2
Bambusa polymorpha	LM1–3, and UM 1–2 from 100 to 1500 m.a.s.l.
Bambusa spinosa (Syn: B. blumeana	CL2–4, LM1–3, and UM1–2 from sea level to 2000 m.a.s.l. Regular pruning of thorny branches is essential to keep clumps in healthy condition.
Bambusa tulda	LM1–3 and UM1–2 from 100 to 1700 m.a.s.l.
Bambusa vulgaris	This species performs well in most zones, particularly when soil moisture is not a constraint. Best suited for CL2–4, LM2–3, and UM1–2 from sea level up to 2000 m.a.s.l. The green variety with superior properties and durability is to be promoted in preference to the more common yellow variety.
Dendrocalamus asper	CL2, LM1–2, and LH3 from sea level to 2000 m.a.s.l.
Dendrocalamus brandisii	LM1–2, LH3, and UM1–2 from sea level to 2000 m.a.s.l.
Dendrocalamus giganteus	LM1–2, LH3, UM1–2 (with reliable rainfall) from sea level to 2100 m.a.s.l.
Dendrocalamus hamiltonii	CL2–4, LM1–2, LH3, and UM2 (with reliable rainfall) from sea level to 2000 m.a.s.l.
Dendrocalamus membranaceus	CL2–4, LM1–3, and UM2 from sea level to 1800 m.a.s.l.
Dendrocalamus strictus	Suited to drier areas. LM 3–5 and CL 2–4 from sea level to 1000 m.a.s.l.
Phyllostachys aurea	LM1–2, UM1–3, and LH1–3 up to 2100 m.a.s.l.
Thyrsostachys siamensis	CL2–4 and LM2 from sea level to 2000 m.a.s.l.

It is to be emphasized that the performance of the species in each of the above-recommended AEZs will depend on the level of management practices adopted, particularly the maintenance of the optimum culm density in the clumps by timely removal of mature and dead culms. A

common observation during visits to the species trial sites and sometimes in the farmers' fields was the lack of any form of clump management, resulting in tightly congested clumps with crooked and dead culms. A decline in productivity and quality of the culms produced is to be expected under such conditions, leading to improper conclusions on the suitability of the species in the location.

7. Potential for value addition in Kenya

No study of the selection of species and its matching to sites is complete without an attempt to match the species with potential applications. To some extent, cultural practices and harvesting methods need to be tuned to obtain the best productivity in terms of biomass as well as in the quality of culms produced.

Construction

Bamboo culms are suitable for environmentally friendly buildings because of their favorable mechanical properties, especially their high strength-to-weight ratio, flexibility, tensile strength, fast renewability, and carbon sequestration ability. The aesthetic appeal of bamboo culms is ideal for ecotourism, disaster relief projects, temporary or semi-permanent kiosks, exhibition halls, and other purposes.

Furniture

Traditional bamboo furniture is not very significant in Kenya. The involvement of professional designers will permit furniture that conforms to trends and promotes competitiveness and access to upmarket clientele.

Edible shoots, beverages, and fodder

Bamboo wine from *Oxytenanthera abyssinica* has received some attention in the media and is promising for replicating in Kenya with other species as it encourages farmers to adopt agroforestry practices. Bamboo leaf tea is another concept that can be borrowed from Asia to take advantage of the purported nutraceutical benefits. There is good potential for use of bamboo leaves as fodder, particularly as a supplement to conventional fodder in lean times.

Charcoal

The fast growth and capability of bamboo to capture CO_2 means that it is regarded as an appropriate plant for climate change mitigation efforts. The conversion of biomass to charcoal for fuel to replace firewood has great implications, mainly because tree felling in the forests is avoided by the use of rapidly renewable bamboo. Technology for efficient conversion and quality control, as well as value addition in the form of pellets and briquettes, will add to Kenya's economy.

Conversion to activated carbon probably imparts the greatest value addition because it is used in the manufacture of several high-value products.

Engineered bamboo

A great potential for high biomass volume to be converted into an industrial product is in the area of engineered bamboo, which is fast becoming a replacement for conventional timber, steel, and plastic in construction, furniture, and household products. The large-diameter species with good wall thickness (*D. asper, D. giganteus, B. blumeana,* and *B. vulgaris*) are suitable.

Landscape restoration

Bamboos' unique combination of features makes them ideal for use as tools for landscape restoration. They are suitable for quick establishment of green cover, and their profuse root systems and underground networks of rhizomes prevent soil erosion, help retain water, and add organic matter to impoverished soils. The multiple uses to which bamboo is put include the replacement of timber, use as food and fodder, and applications for engineered bamboo, while as biofuel, bamboos contribute to economic activity and livelihood development.

8. Recommendations

The preliminary assessment of the suitability of native, naturalized, and introduced species in various locations in Kenya has revealed the potential of some bamboo species for commercial exploitation. To demonstrate the full potential under proper management practices before large-scale propagation and establishment of plantations, the following is recommended:

- Introduce new germplasm of the selected exotic species from provenances in the native region that match the climatic parameters of the selected AEZs of Kenya.
- Establish new demonstration trials to test the effects of spacing and standardize management practices for different types of bamboo plantations.
- Evaluate agroforestry models appropriate for the dominant agricultural practices in each AEZ.
- Carry out an extensive evaluation of variation in native species throughout the distribution range to identify suitable landraces for conservation and commercial exploitation for specific end uses.
- Standardize large-scale clonal propagation technology for the selected species for adoption by commercial nurseries.
- Adopt a certification scheme for quality planting materials and nurseries.

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