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Biotechnological Advances in Bamboo

The "Green Gold" on the Earth

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Professor Xiong Wenyu
(July 1915–September 2014)

Founder of Scientific Cultivation of Bamboo Plantation
Known as "Mr. Bamboo" *and* "Bamboo Pioneer"

Foreword

Bamboos are considered as the "green gold of the forest" as these have improved many facets of rural livelihood while strengthening urban sector. Bamboos have been traditionally used as construction material for rural housing, food, and, last but not least, handicraft products. In today's times, however, its uses have become more diverse. Presently, bamboos have emerged as one of the most important renewable resources for food, fuel, paper, pulp, textile, plywood, etc. Therefore, the annual demands for bamboos have already outcrossed the annual yields across the world. And the current scenario has forced scientists to pay more attention to the utilization of biotechnological tools for better understanding and improving bamboos. Modern biotechnologies are more and more applied in bamboo research and practice and will bring deep influence on the development of bamboo. The concerns in this book initially begin with a chapter introducing the global distribution of the bamboo. The book provides an overview of the adoption of biotechnological approaches to advance bamboo research for better utilization of bamboo resources for human beings. Various applications of biological techniques related to bamboo have been discussed in detail, for example, plant tissue culture techniques, somatic embryogenesis, germplasm conservation techniques, utilization of molecular markers, transcriptomics, polymorphism, and phylogenetic analysis. The book also addresses novel industrial applications of bamboo in structural, food and pharmaceutical applications along with traditional uses in detail. The book is a reference text with essential information for various scientists, including advanced students, teachers as well as research scientists working in different areas of bamboo research.

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Walter Liese

Preface

Bamboo is considered as a multipurpose plant and has a prolonged history as an adaptable and extensively used renewable resource in conventional and commercial applications. Therefore, the annual demands for bamboos have already outcrossed the annual yields across the world. Increasing population pressure; indiscriminate exploitation by paper, pulp, and fuel industry; and insufficient attempts to replenish and cultivate bamboos are further widening the gap between demand and supply. And the current scenario has forced scientists to pay more attention to the utilization of biotechnological tools for better understanding and improving bamboos. As a result, new insights into bamboos were gained through various biotechnological approaches. The book provides an overview of the adoption of biotechnological approaches to advance bamboo research for better utilization of bamboo resources for human beings. Various applications of biological techniques related to bamboo have been discussed in detail, for example, plant tissue culture techniques, somatic embryogenesis, germplasm conservation techniques, utilization of molecular markers, transcriptomics, polymorphism, and phylogenetic analysis. Being involved in this area, we comprehend that information on the application of the biotechnological approaches in bamboo is still obscure, and there is no single book available on this aspect. This volume comprises several chapters on relevant topics contributed by experts working in the field of plant biotechnology so as to make available a comprehensive treatise designed to provide an in-depth analysis of the subject in question. The book is a compilation of 20 chapters with relevant text, tables, and illustrations describing the experimental work on bamboo biotechnology, which will be useful in the planning and execution of various experiments smoothly and effectively. The present book aims to induce new outlooks to scientists/researchers who are unfamiliar with bamboo biotechnology and will be very helpful in various present and future researches in different areas of plant biotechnology, molecular biology, and plant physiology. We are extremely thankful to all the contributors who

wholeheartedly welcomed our invitation and agreed to contribute chapters to embellish information on bamboo biotechnology, thus helping in this endeavor.

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Contents

Chapter 1
Bamboo: Origin, Habitat, Distributions and Global Prospective

Zishan Ahmad, Anamica Upadhyay, Yulong Ding, Abolghassem Emamverdian, and Anwar Shahzad

Abstract Bamboo is the multifunctional and fastest-growing plant on Earth. Bamboo has played a crucial role in the daily life of millions of people in tropical countries, where it provides environmental, social and economic benefits. Bamboo belongs to the subfamily Bambusoideae of the grass family Poaceae. Today, the native bamboo distributes mainly in Asia, America and Africa, but Europe is unable to claim any native bamboo species. Approximately 123 genera and more than 1500 species of bamboo plant have been identified across the world. The natural distribution of bamboo across the tropical and subtropical regions is dependent on the type of soil, rainfall, temperature and altitude. The latitudinal distribution of bamboo ranges from 47° S to 50° 30′ N, while the altitudinal distribution from sea level to 4300 m. The occurrence of bamboo is therefore associated with the area mostly mesic to wet forest types in both temperate and tropical regions. However, there are some other bamboos reported to be adapted for open grasslands or narrow habitat. The present chapter is aiming to summarize the details of bamboo origin, habitat and global distribution. The classification of Bambusoideae has been also given. Moreover, an overview of important bamboo genera and species has been discussed.

Keywords Bamboo diversity · Bamboo habitats · Bamboo classification · Woody bamboo

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1.1 Introduction

Bamboo is a versatile group of plants that comes under the subfamily Bambusoideae of the family Poaceae. From the beginning of civilization up to nowadays, bamboo has played an immensely important part in the daily lives of human beings, and therefore, this plant is known as "the plant of multifunctional uses" (Amada and Untao 2001; Wooldridge 2012; Sharma et al. 2014). Bamboo grows fast and matures early, due to which, its plantation is good over other forestry species. One more significant advantage in comparison to other forest plant species is that bamboo can harvest multiple times within a few years because of its fast growth rates. Nowadays, the native bamboo distributes mainly in Asia, America and Africa. There is no native bamboo species in Europe; nevertheless, a lot of species were introduced and cultivated in Europe. The use of bamboo stem is wide, and its major quantity is utilized as raw material for housing, utensils, agricultural applications, handicraft items, packing materials, paper and pulp industry, etc. (Singh 2008). Bamboo is inextricably linked to human beings as it fulfils the need for shelter, clothing and many other items (Wooldridge 2012; Chaowana 2013). Therefore, commonly, bamboo described as "friend of people", "poor man's timber", "green gasoline" and "the cradle to coffin timber" (Singh 2008). Bamboo serves as an important resource for living organisms like pandas and many other organisms.

The distribution of bamboo plants over the subtropical and tropical regions naturally depends on several conditions like rainfall, soil type, temperature and altitude. Bamboos naturally grow in those areas that receive annual rainfall and vary from 1200 to 4000 mm approximately, and the annual average temperature varies from 8 to 36 °C approximately. They grow well in different types of soils like sandy soils, loamy soils, hard lateritic soils and rich alluvium soils. Except Antarctica and Europe, bamboos are native to all continents and distributed 47° S to 50° 30′ N latitudinal and 4, 300 m from the sea level in altitude (Judziewicz et al. 1999; Ohrnberger 1999). The multipurpose application of bamboo hardly rivalled with other plants of plant kingdom. However, bamboos are complex plants and difficult to identify and classify, but considering the ecological and economic importance, the correct identification and classification are a critical step. This chapter deals with the up-to-date information of bamboo origin, habitat and its global prospective. Bamboo taxonomical identification and classification system on the basis of morphological and molecular characteristics has been also discussed. Moreover, the end section of this chapter provides an overview of important bamboo genera and species.

1.2 Bamboo Origin, Habitat and Diversity

The origin of bamboo will be discussed based on the evolution of the grass, distribution centre, fossil evidence and the basal lineage of grass. It deals with where and when its origin and the possible ancestor. The utilization of bamboo

can be dated back to 3500 years ago. In order to better use bamboo, the ancient people started to give names of different bamboos. The first monograph of bamboo named "Zhu Pu" in the world was written by Dai Kai-zhi (317–420 A.C.) from Jin Dynasty. In his book, the morphological and biological characters, distributions and usages of more than 60 bamboos were described. He also modified the definition of bamboo from grass to "Bamboo is a non-wood, non-grass strange plant".

In fact, the English word bamboo" in west literature was originated from the Indian name "Mambu". In India, the local people collected one kind of substance from a plant named "Mambu" or "Saccar Mambu" as medication which was called "Tabaxir" later. In fact, the first bamboo classification in Europe was done by Georg Eberhard Rumpf (1750) who divided the bamboos into eight classes, all with the name Arundo. On this basis, Linnaeus in 1753 used the name *Arundo bambos* which included all bamboos up to his time, from which the genus name *Bambusa* was later adapted. This classification system was used with little change by Linnaeus (1753). The number of bamboo species known to science has risen sharply since Linnaeus published only one species, *Arundo bambos* (*Bambusa bambos*), in his *Species Plantarum*. One hundred fifteen years later (1868), a new list of 170 species and 21 genera of bamboo was issued by Munro who published a monograph of the Bambuseae and classified the bamboo in three divisions.

In 1881, Gamble proposed a classification system in which he recognized 4 subtribes, 14 genera and 151 species. In 1883, Bentham and Hooker, *Genera Plantarum* 3 (2), Bambuseae, modified the system of Munro, so instead of three divisions, four subtribes were introduced. About 30 years later (1913), French botanist E.G. Camus adopted Munro's system of classification. In his publication, he listed 33 genera and 490 species of bamboo, including many of the herbaceous bamboos. During the 1980s–1990s, a few bamboo classification systems were published by Clayton and Renvoize (1986), Soderstrom and Ellis (1987), Dransfield and Widjaja (1995) and Stapleton (1998). More recently, a new system based on the molecular data was built by Kelchner and Bamboo Phylogeny Group (2013). According to Ohrnberger (1999), a number of species of woody bamboos purely occurring in the countries of the Asia-Pacific region, Africa and Americas have been listed in Table 1.1.

Bamboo plant species is naturally distributed globally in all continents except Antarctica and Europe; however, a few years ago, some species of bamboo plants had been introduced in Europe (Akinlabi et al. 2017; Wu et al. 2020). In terms of altitudinal and latitudinal, distribution of bamboo plants ranges from sea level to 4300 m and 47°S to 50°30′N, respectively (Soderstrom and Calderon 1979, Ohrnberger 1999, Judziewicz et al. 1999, Liese and Tang 2015). In an ecological area, bamboo plants are dominant in subtropical and tropical regions (Ohrnberger 1999, Jiang 2007, Akinlabi et al. 2017, Wu et al. 2020). However, its occupancy also includes coniferous forests, temperate deciduous forests, mountainous forests, lowland tropical forests, wetter forests, grasslands, etc., and therefore bamboo plants occupied a broad range of habitat types. A description of bamboo species occurrence and habitats has been summarized in Table 1.2.

Bamboo has the richest diversity in Asia. There are about 50 genera and 900 species which is about 75% of the total species in the world. The largest national complement of species is for China, which had about 600 described species,

Table 1.1 Naturally occurring bamboo species

	Country	Number of naturally occurring bamboo species
Asia-Pacific	Australia	2
	Bhutan	1
	Brunel	1
	China	583
	Hong Kong	3
	India	40
	Indonesia	29
	Japan	75
	Republic of Korea	2
	Laos	4
	Malaysia	26
	Myanmar	30
	Nepal	6
	Papua New Guinea	15
	Philippines	14
	Sri Lanka	6
	Thailand	4
	Vietnam	38
Africa	Madagascar	32
	Tanzania	1
North, Central and South America	Argentina	2
	Belize	1
	Bolivia	2
	Brazil	110
	Chile	10
	Colombia	15
	Costa Rica	13
	Cuba	6
	Ecuador	14
	El Salvador	1
	Guyana	2
	Martinique	1
	Mexico	17
	Panama	1
	Paraguay	1
	Peru	15
	Trinidad and Tobago	2
	United States	1
	Uruguay	1
	Venezuela	32

Table 1.2 Bamboo species occurrence and habitats

Bamboo species	Occurrence	Habitats	References
Acidosasa	Asia	Dry or evergreen subtropical forests	Stapleton (1994a, b, c), Li and Xue (1997), BPG (2012)
Actinocladum	Brazil	Lowland bamboos	Soderstrom and Calderon (1979), Judziewicz et al. (1999)
Alvimia	America, Asia	Lowland tropical bamboos	Soderstrom and Londoño (1988), Dransfield (1992, 1994)
Arundinaria	Eastern United States, China, Japan, North America	Woodlands and forests, mostly along rivers	Yang and Xue (1990), Triplett et al. (2006), Dai et al. (2011)
Aulonemia	Brazil	Andean montane forests, mono-dominant stands at high elevations	Judziewicz et al. (1999), Viana et al. (2013)
Bambusa	China, Mexico, India, Vietnam	Lowland moist tropical forests, lower montane forests	Soderstrom and Calderon (1979), Seethalakshmi and Kumar (1998), Judziewicz et al. (1999), BPG (2012)
Bashania	China	Montane forests	Taylor and Qin (1997), Li and Xue (1997)
Bergbambos	India, South Africa, Sri Lanka	Tropical mountain grasslands and shrublands	Soderstrom and Ellis (1982); Soderstrom et al. (1988)
Cambajuva	Brazil	Mono-dominant stands at high elevations	Judziewicz et al. (1999), Viana et al. (2013)
Chimonobambusa	China, Myanmar	Montane forests, wetter side of mountain ranges	Stapleton (1994a, b, c), Taylor and Qin (1997), Li and Xue (1997)
Chusquea acuminatissima, *C. aristata*, *C. tessellate*, *C. guirigayensis*, *C. villosa*	America, Argentina, Brazil, Chile, Mexico,	Andean montane forests, *Araucaria* forests, Atlantic forests, cloud forest, highest elevation (4000–4400 m), montane forests, *Nothofagus*, pine oak fir forests	Soderstrom and Londoño (1988), Dransfield (1992, 1994), Judziewicz et al. (1999), Fisher et al. (2009), BPG (2012)
Cryptochloa	Argentina, Brazil, America, Mexico	Lower montane forests	Judziewicz et al. (1999), Judziewicz and Clark (2007)

(continued)

Table 1.2 (continued)

Bamboo species	Occurrence	Habitats	References
Dendrocalamus strictus	America, China, Colombia, India, Madagascar, Mexico	Lowland moist tropical forests or lower montane forests	Soderstrom and Calderon (1979), Gadgil and Prasad (1984), Rao and Ramakrishnan (1988), Seethalakshmi and Kumar (1998), Judziewicz et al. (1999), Ruiz-Sanchez (2011), BPG (2012)
Dinochloa	America, Asia	Lowland tropical bamboos	Soderstrom and Londoño (1988), Dransfield (1992, 1994)
Drepanostachyum	Asia, Central Himalayas	Evergreen subtropical forests, seasonally dry forests	Stapleton (1994a, b, c), Li and Xue (1997), BPG (2012)
Ekmanochloa	America, Argentina, Brazil, Mexico, West Indies	Savannas (semi-deciduous seasonal forests)	BPG (2012), Ferreira et al. (2013)
Eremocaulon	Mexico	Lowland moist tropical forests or lower montane forests	Soderstrom and Calderon (1979), Seethalakshmi and Kumar (1998), Judziewicz et al. (1999), BPG (2012)
Fargesia	Asia, China, Japan, Madagascar, Sri Lanka	Montane forests, temperate mountains	Li and Xue (1997), Taylor and Qin (1997), Li et al. (2006), BPG (2012)
Fargesia yulongshanensis	China, Himalaya	Might elevations	Li et al. (2006)
Filgueirasia	Brazil	Lowland bamboos	Soderstrom and Calderon (1979), Judziewicz et al. (1999)
Gigantochloa	China, Mexico	Lowland moist tropical forests or lower montane forests	Soderstrom and Calderon (1979), Seethalakshmi and Kumar (1998), Judziewicz et al. (1999), BPG (2012)
Guadua paniculata	Amazon Basin, America, China, Colombia, India, Mexico, Madagascar	Lowland moist tropical forests or lower montane forests	Soderstrom and Calderon (1979), Gadgil and Prasad (1984), Rao and Ramakrishnan (1988), Seethalakshmi and Kumar (1998), Judziewicz et al. (1999), Ruiz-Sanchez (2011), BPG (2012)

(continued)

Table 1.2 (continued)

Bamboo species	Occurrence	Habitats	References
Hickelia	America, Asia	Lowland tropical bamboos	Soderstrom and Londoño (1988), Dransfield (1992, 1994)
Holttumochloa	Southeast Asia	Montane forests	Dransfield (1992), Wong (1993)
Indosasa	Asia, China	Montane forests, dry or evergreen subtropical forests	Stapleton (1994a, b, c), Li and Xue (1997), Taylor and Qin (1997), BPG (2012)
Kuruna	India, South Africa, Sri Lanka	Tropical mountain grasslands and shrublands	Soderstrom and Ellis (1982); Soderstrom et al. 1988
Lithachne	Brazil, America, Colombia, Cuba, Mexico, Panama	Near the equator, lower montane forests	Judziewicz et al. (1999), Judziewicz and Clark (2007), BPG (2012)
Merostachys	Brazil	Atlantic forests	Judziewicz et al. (1999)
Nastus borbonicus	Argentina, Chile	Montane forests	Judziewicz et al. (1999), BPG (2012)
Neomicrocalamus	America, Asia	Lowland tropical bamboos	Soderstrom and Londoño (1988), Dransfield (1992, 1994)
Ochlandra	Asia, Africa, Australia, India, Sri Lanka	Reed-like thickets along stream banks	Seethalakshmi and Kumar (1998), BPG (2012), Gopakumar and Motwani (2013)
Olyra (*O. latifolia*)	Argentina, America, Brazil, Colombia, Cuba, Panama Mexico	Near the equator, lower montane forests	Judziewicz et al. (1999), Judziewicz and Clark (2007), BPG (2012)
Otatea	America, Colombia, India, Mexico, Madagascar	Drier forests	Soderstrom and Calderon (1979), Gadgil and Prasad (1984), Rao and Ramakrishnan (1988), Seethalakshmi and Kumar (1998), Ruiz-Sanchez (2011)
Pariana	Amazonian, America, Argentina, Brazil, Bolivia, Costa Rica, Mexico	Lowland tropical montane forests	Judziewicz et al. (1999), Judziewicz and Clark (2007)
Perrierbambus	America, Colombia, India, Mexico, Madagascar	Drier forests	Soderstrom and Calderon (1979), Gadgil and Prasad (1984), Rao and Ramakrishnan (1988), Seethalakshmi and Kumar (1998), Ruiz-Sanchez (2011)

(continued)

Table 1.2 (continued)

Bamboo species	Occurrence	Habitats	References
Raddiella (*R. esenbeckii*)	America, Argentina, Brazil, Mexico	Lower montane forests	Judziewicz et al. (1999), Judziewicz and Clark (2007)
Racemobambos	Southeast Asia, America	Montane forests, lowland tropical bamboos	Soderstrom and Londoño (1988), Dransfield (1992, 1994), Wong (1993)
Reitzia	Brazil	Atlantic forests	Judziewicz et al. (1999)
Rhipidocladum	Brazil	Andean montane forests	Judziewicz et al. (1999)
Sasa	China, Korea and Japan	Wetter forests	Noguchi and Yoshida (2005), Tsuyama et al. (2011)
Sasamorpha	China, Korea and Japan	Wetter forests	Noguchi and Yoshida (2005), Tsuyama et al. (2011)
Sarocalamus	China	Wetter side of mountain ranges	Stapleton (1994a, b, c)
Schizostachyum	China, Mexico	Lowland moist tropical forests or lower montane forests	Soderstrom and Calderon (1979), Seethalakshmi and Kumar (1998), Judziewicz et al. (1999), BPG (2012)
Sinobambusa	Asia	Dry or evergreen subtropical forests	Stapleton (1994a, b, c), Li and Xue (1997), BPG (2012)
Thamnocalamus	Central Himalayas	Seasonally dry	Stapleton (1994a, b, c)
Vietnamosasa	Indochina	Grassland	Stapleton (1998)
Yushania	Asia, China, Japan, Madagascar, Sri Lanka	Montane forests, wetter side of mountain ranges, temperate mountains	Stapleton (1994a, b, c), Li and Xue (1997), Taylor and Qin (1997), Li et al. (2006), BPG (2012)

followed by India (102 species) and Japan (84 species). The bamboo area in Asia is about 25 million hm^2; among them, India ranks first with about nine million hm^2, while China has about 6.4 million hm^2. Myanmar, Indonesia, Malaysia, Vietnam, Laos, Cambodia, Philippines, Thailand, Japan, Bangladesh, South Korea, Sri Lanka, Nepal and other countries have about ten million hm^2. In America, there are 21 genera and 345 species, but it mainly distributes in Latin America, with only 3 species in southeast part of the United States. However, the biodiversity of bamboo is the richest in this region. In Africa, about 13 genera and 40 species were recognized. But the bamboo forests distribute mainly in East Africa, like Tanzania, Kenya, Zambia, Ghana, Ethiopia, Uganda, Mozambique and Madagascar.

1.3 Taxonomical Identification of Bamboo

As bamboo is a highly adaptable plant in different environmental conditions, it is difficult to identify or classify. Moreover, on the basis of ecological characteristics and the economic importance, identification of bamboo species was done. In the whole world, approximately 123 genera and more than 1500 species of bamboo plant have been identified (Steinfeld 2001; Nguyen 2006; Chaowana 2013). Bamboo belongs to the monocotyledonous flowering plants in the group angiosperms. Bamboo plant is basically divided into two major parts, the underground part of stem known as rhizomes and the upper portion, i.e. stem known as culms (Steinfeld 2001). Rhizomes of the bamboo are mostly sympodial, and they store the nutrients for their growth and development along with the sustenance of the plant in the ground. Rhizomes also contain the meristematic buds which further grow into shoots and emerge from the ground to form the group of culms. The culm of the bamboo plant is cylindrical in shape and contains most of the woody material of the plant (Ahmed and Kamke 2005). The culm is subdivided by multiple sections which are called nodes or diaphragms, and the part of the culm is between the two adjacent nodes called internodes (Amada and Untao 2001). Bamboo culm is hollow and has a thick wall, due to which, it ideals with the formation of household products, etc. The diameter of bamboo culm is ranging from 0.64 to 30.48 cm, and its height ranges from 1 foot to 120 feet (Amada and Untao 2001). Bamboo culm does not have bark, but it has smooth outer skin which is hard in nature because of the presence of silica. Bamboo culms bear branches and foliage leaves. Species of bamboo differ from each other in the sense of growth style of culm, i.e. it may be erect with droopy tips or simple erect, and also, it may be arched or clambering type (Akinlabi et al. 2017). Bamboo has the main characteristic of having high tensile strength compared to mild steel for the load-bearing capacity, and this is because bamboo has a natural composite material made up of cellulose fibres which immersed in a matrix of lignin that gives of an average 700 MPa tensile resistance (Janssen 2000; Li and Shen 2011).

1.4 Classification of Bamboo

On the basis of morphological as well as molecular characteristic features, bamboo is classified into three tribes, namely, Arundinarieae, Bambuseae and Olyreae. Arundinarieae includes temperate woody bamboos, Bambuseae includes tropical bamboos, and Olyreae includes herbaceous bamboos (Sungkaew et al. 2009; BPG 2012; Kelchner and Bamboo Phylogeny Group 2013). Recently, bamboos (i.e. Bambusoideae) is considered as part of the subfamily of Poaceae, i.e. Grasses family (GPWG 2001; GPWG II 2012), and these are found to be the most diversified grasses in the global forests (Zhang and Clark 2000; Judziewicz and Clark 2007; Sungkaew et al. 2009). According to GPWG (2001) and BPG (2012), there are approximately 115 to 119 genera and more than 1500 species of bamboos where

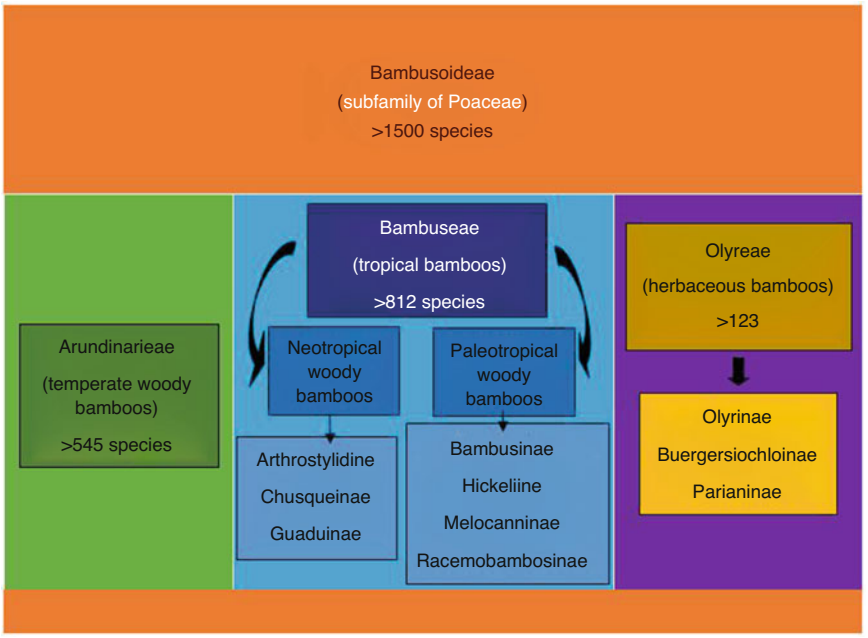

Fig. 1.1 Classification of Bambusoideae

Arundinarieae consists of about 533 to 546 bamboos, Bambuseae contains about 784–813 bamboos and Olyreae has only about 122–124 bamboos (Fig. 1.1). Tribe Bambuseae is further subdivided into two clades, namely, neotropical woody bamboos and paleotropical woody bamboos. Neotropical woody bamboos are again categorized into three subtribes, namely, Arthrostylidium, Chusqueinae and Guaduinae. Paleotropical woody bamboos are categorized into four subtribes, namely, Bambusinae, Hickeliinae, Melocanninae and Racemobambosinae. Further, tribe Olyreae are subdivided into three subtribes, namely, Olyrinae, Buergersiochloinae and Parianinae. Morphologically, woody bamboos can be distinguished from the herbaceous bamboos as they have lignified culms, culm leaves and outer ligules, while herbaceous bamboos are made up of weekly lignified culms only (BPG 2012). Moreover, woody bamboos have the characteristic feature of monocarpic flowering with bisexual spikelets, while herbaceous bamboos have unisexual spikelets with seasonal flowering. Furthermore, olyroid silica found in the herbaceous bamboos is absent in the case of woody bamboos.

1.5 Bamboo Culm and Its Development

The culm is the main material for utilization. It can reach the maximum height in about 60 days. So, bamboo is considered the most fast-growing plant. No matter it is a sympodial or monopodial bamboo, a culm is only one piece of the branch of one

ramet. It developed from the buds on the rhizome or on the culm prope. Some bamboo species are shooting in spring, some in summer and some in autumn. The differentiation of the buds may be affected by temperature and the endogenous hormone.

The most important process of culm development includes bud differentiation, primary thickening growth, elongation growth and maturation. There are already quite a lot of publications that deal with the development of the culm, but there still remain a lot of questions which need to continue the investigation. For example, the culm sheath plays an important role by shoot elongation growth. But there are very few little publications that deal with this aspect. During the primary thickening, how the vascular bundles differentiate remains unknown. The mechanism of the fibre thickening during the maturation of culm is still a mysterious matter. Culm development occurs in two phases: (1) Newly unbranched shoots having culm leaves that elongate to their full length takes place. (2) Elongated culm lignification and development of branches along with the production of foliage leaves take place. The longevity of culms is varied among species to species, but generally they persist for 5–10 years (McClure 1966), and usually 3–5-year-old culms are treated as mature culms. The age of culms is an important parameter in the management of bamboo forest. Moreover, the age of bamboo can also be determined by counting the base node (leaf scar) on the leaf sheath present in the twig of a culm of bamboo (Banik 2000). Leaves of a bamboo fall in 1 year or 1 ½ year, and new leaves are developed from the near one node of leaf fall region keeping leaf scar marks on twig. Therefore, within 12–15 months of culm age, mark of one leaf scar is formed, and after in the next 24–30 months of culm age, another mark of leaf scar is formed. Therefore, in the third year of culm age, total three marks of leaf scar are formed in the twig.

1.6 Difference in Characteristics of Bamboo in Reference to Trees

"In the plant kingdom, there is one kind of plant called bamboo, which is different from both trees and grasses. It is a strange plant". This definition was described by Dai Kaizhi (AC 420–479), who write the first monograph of bamboo. Bamboo is evergreen with a special leaf blade. The anatomical structure is also different from those of grass. Bamboo has no secondary growth. Bamboo has a special branching pattern and has no main trunk. Bamboo has a very long vegetative growth cycle and propagates mainly by clones. A differential description of bamboo and trees is summarized in Table 1.3.

Table 1.3 Differences in the characteristic features of bamboos and trees

S. No.	Bamboos characteristics	Tree characteristics
1	Stem, i.e. culm is hollow and segmented	Stem is solid and unsegmented
2	Peripheral region of the culm is the hardest part of the plant	Central region of the stem is the hardest part of the plant
3	Culm has no bark	Stem has bark (secondary phloem + cork)
4	Culm grows very fast and reaches its full height in a single season (as its height reaches up to 36 m tall within 4–6 months)	Stem grows slowly in height as well as in diameter for many seasons
5	Conducting tissues, i.e. xylem and phloem lie together inside the vascular bundle	Conducting tissues, i.e. xylem and phloem are separated by vascular cambium inside the vascular bundle
6	Due to the absence of vascular cambium, culm does not grow in diameter with the age	Due to the presence of vascular cambium, stem grows in diameter with the age
7	Harvesting of culms directly effects on the clump community	Harvesting of stems does not directly affect on the remaining tree
8	Culm depends on the other in a clump because it grows in association with the network of rhizome	Stem grows independently
9	Culm has no radial, i.e. lateral, communication except at the internodes	Stem has radial communication throughout its length
10	Underground part consists of both rhizome and roots	Underground part does not have rhizome and consist of only roots

1.7 An Overview of Important Genera and Species of Bamboos

There are 123 genera and more than 1500 species of bamboos in the world (GPWG 2001; BPG 2012; Steinfeld 2001; Nguyen 2006; Chaowana 2013). They are native to Asia, America, Africa and Oceania. The most important feature of bamboos is being sympodial and its discrete clump form. A brief description of some important bamboo genera and species has been given in Table 1.4. Similarly, the important species of high economic use in China, South America and Africa has been listed below.

Phyllostachys edulis, the most important bamboo in China (Fig. 1.2). *Phyllostachys violascens*, an important shoot production bamboo in Yangtze Delta region (Fig. 1.3). *Dendrocalamus latiflorus* and *Bambusa oldhamii*, two important shoot production bamboos in South China (Figs. 1.4 and 1.5). *Dendrocalamus brandisii* an important shoot production bamboo in south Yunnan Province (Fig. 1.6). *Chimonobambusa utilis*, an important shoot production in southwest China (Fig. 1.7). *Dendrocalamus farinosus*, *Bambusa rigida* and *Bambusa emeiensis*, important species for pulp industry in China (Figs. 1.8, 1.9 and 1.10). *Guadua angustifolia*, the most important species for construction in South America

Table 1.4 Overview of some important genera and species of bamboos

Genus	Species	Characteristic features		
		Geographical distribution	Brief description	Uses
Bambusa	*B. arundinacea*	Bangladesh, China, India, Indonesia, Myanmar, Nepal, Philippines, Thailand, Vietnam	It is a versatile bamboo, having thick culm internodes. It is thorny in nature. Its culm height is up to 30 m, thickness about 18 cm and wall thickness approx. 2.5 to 5 cm. It can withstand 2 °C temperature	Culm used in artefacts, pulp and paper industry, handicrafts, river bank stabilization, land rehabilitation
	B. balcooa	Australia, Bangladesh, India, Indonesia	Its culm height is up to 24 m, diameter up to 15 cm and wall thickness approx. 2.5 cm	Culm used in construction of artefacts, pulp and paper, furniture, handicrafts, river bank stabilization, land rehabilitation
	B. blumeana	China, Borneo, Java, Malaysia, Philippines, Papua Guinea, Sumatra, Thailand	It is a giant thorny bamboo and green in colour with prominent nodes. Its culm height is up to 15–25 m and diameter up to 20 cm. They can be propagated by seeds, layering, culm and rhizome cuttings	Culms used in construction of artefacts, handicrafts, furniture, pulp and paper, chopsticks, river-bank stabilization, rehabilitation of degraded land
	B. polymorpha	Bangladesh, India, Myanmar, Thailand	Its culm height up to 16 and 25 m, diameter up to 15 cm and its wall thickness up to 1 cm. It can be propagated by seeds, layering, culms, offset and rhizome cuttings	Culms used in construction of artefacts, handicrafts, furniture and buildings. Its shoots are edible also
	B. textilis	China	It is a medium-sized bamboo. Its cum height is up to 15 m and diameter up to 3–5 cm. Its wall is thin and delicate in nature. It can be propagated by seeds, culms and offset cuttings	It is a high-quality bamboo. Culm is used in artefacts, handicrafts and weaving purpose because it splits easily. Its shoots are edible also

(continued)

Table 1.4 (continued)

Genus	Species	Characteristic features		
		Geographical distribution	Brief description	Uses
	B. tulda	Bangladesh, India, Indonesia, Myanmar, Nepal, Thailand, Vietnam	Its culm height is up to 30 m, diameter up to 5–10 cm and wall thickness approx. 1 cm. It can be propagated by seeds, marcotting, culms, rhizomes and offset cuttings	Culms used in construction artefacts, paper and pulp, handicrafts, furniture and architectural works
	B. vulgaris	Found in all regions where bamboo can grow easily, i.e. temperate, tropical and subtropical regions	This bamboo is strong and medium to large with having open clumps. Its culm height is up to 20 m, diameter up to 5–10 cm and wall thickness approx. 1.5 cm. This bamboo is easy to propagate because it is tremendously vegetative in nature, and therefore it mostly propagated by branch cuttings, layering, marcotting and culm, offset and rhizome cuttings. Its culms and internodes are curved. This species is of two varieties. One is *B. vulgaris vittata* and characterized by having yellow culm, and the other is *B. vulgaris wamin* and characterized by having green culm. These are grown as ornamental plants	Culms used in construction of artefacts, furniture, handicrafts, architectural works and manufacturing of pulp and paper
Cephalostachyum	*C. pergracile*	China, India, Java, Myanmar, Thailand	It is a medium-sized bamboo and is having straight culms. Its culm height is up to 30 m and its wall is thin. They can be propagated by using seeds but mostly propagated	Culms used in construction of artefacts, handicrafts and weaving of baskets. It used as an ornamental plant also

			by culm and offset cuttings because it is tremendously vegetative species	
Dendrocalamus	*D. asper*	Bangladesh, China, India, Indonesia, Laos, Malaysia Myanmar, Nepal, Philippines, Thailand, Vietnam	These bamboos possess large culms whose height is up to 20–30 m, diameters up to 8–20 cm and wall thickness approx. 2 cm. It can be propagated by culm, offset and branch cuttings	Culms used in construction of artefacts, handicrafts, furniture, musical instruments and architectural works Its shoots are edible also
	D. giganteus	Bangladesh, China, Ghana, India, Indonesia, Kenyan, Myanmar, Philippines, Thailand, Vietnam	This bamboo is made up of huge and large culm and green to dark bluish green in colour. Its culm height is up to 25–60 m, diameter up to 10–20 cm and wall thickness approx. 2.5 cm. It can be propagated by layering, marcotting, macroproliferation, culms, branch and rhizome cuttings	Culms used in construction of artefacts, handicrafts, structural works, building,bamboo boards and pulp. Its shoots are edible also
	D. lactiferous	China, India, Japan, Myanmar, Philippines, Taiwan, Thailand, Vietnam	This bamboo is having medium-sized culms. It grows well in areas with high rainfall. Its culm height is up to 14–25 m, diameter up to 8–20 cm and wall thickness approx. 0.5–3 cm. It can be propagated by marcotting, layering and culm cuttings	Culm used in construction of artefacts, handicrafts, furniture, pulp and architectural works
	D. strictus	India, Myanmar, Nepal, Thailand	This bamboo has medium-sized culm. Its culm height up to 8–20 m and diameter up to 2.5–8 cm, and its wall is thick but not straight. It can be propagated by seeds,	Culms used in construction of artefacts, handicrafts, structural works, bamboo boards, building, pulp and household utensils. Its shoots are also edible

(continued)

Table 1.4 (continued)

Genus	Species	Characteristic features		
		Geographical distribution	Brief description	Uses
			layering, marcotting, macroproliferation and culm and rhizome cuttings	
Gigantochloa	*G. apus*	India, Indonesia, Malaysia, Myanmar, Thailand	This is a large bamboo. Its culm height is up to 8–30 m, diameter up to 4–13 cm and wall thickness approx. 1.5 cm which is strongly tufted in nature. It is propagated by culm and offset cuttings	Culm used in construction of artefacts, handicrafts, musical instruments, structural works, building, pulp and household utensils. Its shoots are edible, but it has bitter in taste
	G. levis	China, Indonesia, Kalimantan, Malaysia, Philippines, Vietnam	This bamboo has large culm. Its culm height is up to 30 m, diameter up to 5–16 cm and wall thickness approx. 1–1.2 cm. It is propagated by culm and offset cuttings	Culms used in construction of artefacts, handicrafts, walls, furniture, pulp and paper, architectural works and household utensils. Its shoots are having high edible quality
	G. pseudoarundinacea	China, India, Java, Malaysia, Sumatra	Its culm height is up to 7–30 m, diameter up to 5–13 cm and wall thickness approx. 2 cm which is strong in nature. It is propagated by culms and branch cuttings	Culms used in construction of artefacts, handicrafts, toothpicks, structural works and household utensils. Its shoots are edible also
Guadua	*G. angustifolia*	Argentina, China, India, Mexico	This is a large bamboo, and it can be easily identified by their aesthetic feature like its dark green culm having white node bands. Its culm height is up to 30 m, diameter up to 20 cm and wall thickness approx. 1.5 cm with strongly tufted	Culms used in construction of artefacts, handicrafts, furniture, pulp, structural works, building and bamboo boards

			in nature. It is propagated by culms and offset cuttings	
Melocanna	*M. baccifera*	Bangladesh, China, India, Indonesia, Myanmar, Vietnam	This is a large bamboo species. Its culm height is up to 10–25 m and diameter up to 5–9 cm, but its wall is thin approx. 0.5–1.2 cm. The important feature of this species is its culm tips are pendulous in nature and this produces the largest fruit in the grass family. It is propagated by seeds and culm cuttings	Culms used in construction of handicrafts, structural works, roofing, walls, weaving of mats, pulp and paper. Its shoots are used in the preparation of liquor, and also it is edible
Phyllostachys	*P. edulis*	China, Europe, Japan, Korea, USA, Vietnam	This species of bamboo is medium to large in size. Its culm height is up to 10–20 m and diameter up to 18–20 cm, having a white waxy covering. It is propagated by seeds and offset cuttings	Culm used in construction of handicrafts and in structural works
Thyrsostachys	*T. siamensis*	Indochina and Myanmar	This bamboo has densely clumped, and its sheath on the culm is obstinate with single white ring below nodes. Its culm height is up to 8–16 m and diameter up to 2–6 cm, and its wall is thin in nature. It is propagated by seeds, macroproliferation and offset cuttings	Culms used in construction of handicrafts, walls, furniture, structural works, pulp and paper. It is also used as an ornamental plant. Its shoots are edible also

Fig. 1.2 *Phyllostachys edulis.* (**a**, **b**) plantation. (**c**, **d**) Shoot culms. PC: Prof. Yulong Ding

(Fig. 1.11). *Oxytenanthera abyssinica*, an important bamboo in lowland found in Africa (Fig. 1.12).