Bambusa spp.

Monograph Project

Agricultural Science

2021 - 2022

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1.0 INTRODUCTION

Bamboo is otherwise known as the common name for the genus *Bambusa*. This species belongs to the grass family and is usually claimed for being one of the fastest growing plants in the world. In many tropical nations of Africa, Asia, and America, bamboo has ecological and cultural significance as it supplies socioeconomic and environmental benefits to many populations. As bamboo continues to regain popularity given its multipurposes for food, building material, energy source, and others, it continues to be rediscovered as a traditional raw material. The "poor man's timber" will be recognized within this document as bamboo possesses wonderful properties that can aid humanity in solving a series of threatening issues such as the energy crisis or underdevleopment.

This monograph will discuss the different aspects of *Bambusa* in general (there will be no focus in a specific species) in a distribution of five chapters. The information will be covered as follows: Chapter 2 will describe bamboo ecology including its affinities, origin, present distribution, environmental factors, and fossil records. Chapter 3 will focus on the biology of the plant consisting of chromosome complement, life cycle and phenology, anatomy and growth habits, reproductive biology, and pests and diseases. Chapter 4 will then delve into production and propagation where the various methods of propagation will be explored as well as the plant's management. Chapter 5 will close off with products and marketing where information about the world trade and potential markets will be aimed at.

2.0 ECOLOGY

2.1 Affinities

Taxonomy[1] (ITIS, 2022)**:**

- Kingdom: *Plantae*
- Subkingdom: *Viridiplantae*[2]
- Infrakingdom: *Streptophyta*[3]
- Superdivision: *Embryophyta*
- Division: *Tracheophyta*[4]
- Subdivision: *Spermatophytina*[5]
- Class: *Magnoliopsida*
- Superorder: *Lilianae*[6]
- Order: *Poales*
- Family: *Poaceae*[7]
- Genus: *Bambusa*

Bamboo plants are **clades**[8] members of the *Poaceae* grass family and belong to one of their 12 subfamilies; *Bambusoideae*, which consists of more than 1482 species classified in 119 genera. This is the "fastest growing perennial, evergreen, arborescent plant," (Yeasmin et al, 2015). These can then be classified into three tribes: *Arundinarieae*, *Bambuseae*, and *Olyreae*. The first are temperate woody bamboos of which there are 546 species, the second are tropical woody bamboos of 812 species, and the last are herbaceous bamboos of which there are 124 species.

These plants are known for their asymmetrical, **invaginated** arm cells in the lead **mesophyll** and their expansive **pseudopetiolate** leaf blades containing **fusoid** cells. (Clark et al, 2015).

[1] Taxonomic hierarchy of Bambusoideae based on ITIS organization.
[2] Green plants
[3] Land plants
[4] Vascular plants, tracheophytes
[5] Spermatophytes, seed plants, phanerogams
[6] Monocots, monocotyledons, monocotyledones
[7] Grasses, graminees
[8] Clade: Group of biological taxa that groups all of the descendants from a common ancestor.

2.2 Origin

Early Poaceae diverging lineages within the family are Anomochlooideae, Pharoideae, and Puelioideae, the second being the earliest lineage from the true spikelt-bearing group. The first fossil evidence for grasses dates back to sometime in between the Paleocene and Eocene ages, yet its diversification began between the late Eocene and early Oligocene ages and an extensive diversification happened by Miocene. Major radiations of grasses dated back to 40-50 million years ago including Bambusoideae. The first petrified bamboo fossil corresponds to the Pliocene age (Pal, 2008).

2.2.1 Taxonomic history

Bamboo classification dates back to 200 years ago. It was first used in art and technology by Chinese scholars, yet early taxonomic studies lied in the Western world. During the last century botanists have worked in regions where the plant has presented more diversity contributing to the study of its evolution. Current comprehensive and phylogenetic bamboo classification systems are based on DNA sequence data and morphological and anatomical studies. (Clark et al, 2015).

2.3 Present distribution

Bamboos are native to every continent except Antarctica and Europe. Their latitudinal distribution goes from 47ºS to 50º 30'N and a longitudinal distribution from the sea level up to 4,300m (Clark et al, 2015). Most bamboo diversity is located in Asia Pacific and South America, although there are at least 5 exemplars found in Africa (Pal, 2008).

Table 2.1.

Distribution of major species richness in Asia Pacific, South America, and Africa (Pal, 2008).

Distribution of major species richness	
Country/continent	Number of species found
China	626
India	102
Japan	84

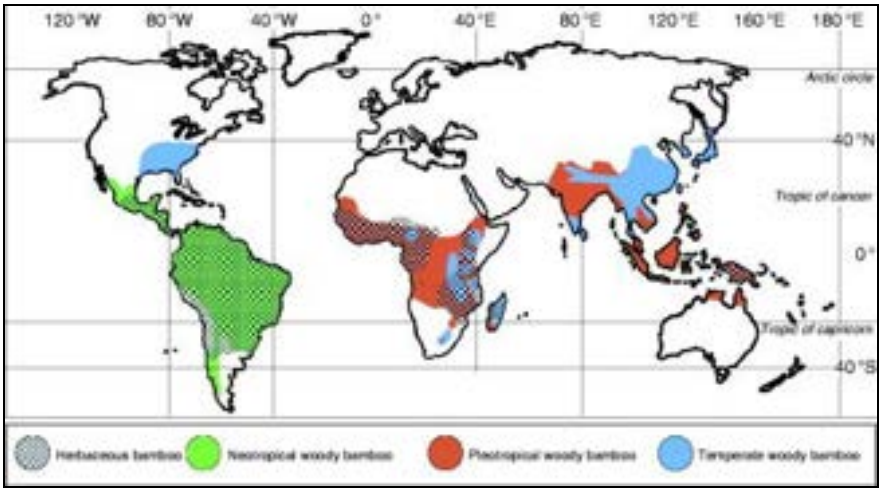
Distribution of major species richness	
Country/continent	Number of species found
Myanmar	75
Malaysia	50
Brazil	134
Venezuela	68
Colombia	56
Africa	5

Herbaceous bamboos ranging around 110 species are mostly found in the Neotropics of Brazil, Paraguay, Mexico, Argentina, and the West Indies. Brazil being the most prominent site reporting 89% of the genera and 65% of species disclosed from the New World. The largest natural bamboo forests extend to 600,000 ha across Brazil, Peru, and Bolivia. Woody bamboos range from 1290 species and are universally distributed with the exception of Europe as it does not contain any native species. These are classified into three groups: paleotropical woody bamboos[9], neotropical woody bamboos[10], and north temperate woody bamboos[11](Pal, 2008).

Figure 2.1.

Distribution of herbaceous, neotropical woody, paleotropical woody, and temperate woody bamboos.

[9] Distributed in tropical and subtropical regions of Africa, Madagascar, India, Sri Lanka, Southern China, Southern Japan, and Oceania.
[10] Distributed in Southern Mexico, Argentina, Chile, and West Indies.
[11] Distributed mostly in the North temperate zone and few at high elevation habitats in Africa, Madagascar, India, and Sri Lanka.



Their habitat types range from forests to temperate or tropical climatic zones. Woody and herbaceous bamboos are recognized as forest grasses, some can even be found in open, grassy, or shrubbery habitats with high elevations in montane tropical systems. *Arundinarieae* are primarily situated in temperate deciduous forests or coniferous forests in temperate subtropical zones in the Northern hemisphere (Eastern Asia and Eastern North America). Temperate bamboos are usually found in the understory and forming the dominant element on the wetter sides. Within China's montane forests species such as *Bashania*, *Chimonobambusa*, *Fargesia*, *Indosasa*, and *Yushania* tend to stand out. In drier areas of the central Himalayas there is a higher prevalence of clump-forming bamboos like *Thamnocalamus* and *Drepanostachyum*. Species such as *Sasa* and *Sasamorpha* can be found in China's, Korea's, and Japan's wetter forests where they tend to be more aggressive and dominate the understory. Temperate Asian species like *Acidosasa*, *Drepanostachyum*, *Indosasa*, and *Sinobambusa* spread into dry or evergreen subtropical forests. In the Eastern United States and the Southeastern Coastal Plain *Arundinaria* appears in woodlands, forests, and along water courses. Generas of larger statures such as *Bambusa, Dendrocalamus, Eremocaulon, Guadua, Gigantochloa,* and *Schizostachyum* flourish in lowland moist tropical forests and lower montane forests that reach 1500 meters in elevation within both Eastern and Western hemispheres. These bamboos lie in valleys, along rivers and streams, typically in secondary forests excluded from other vegetation. Several "lowland tropical bamboos tend to have smaller culms which twine around or scramble over trees and shrubs, or form curtains of hanging foliage." *Ochlandra* species construct reed like thickets as a form of self defense along their stream banks. Lowland species in India, Latin America, Mexico and

Colombia, and Madagascar adapt to drier forests. Lowland bamboos in Brazil, Indochina are adapted to both droughts and fire as a form of survival in grassland habitats. Natural tropical bamboo species forests are spread across the Amazon Basin, although they are also associated with moist tropical montane forests with elevations above 1500 meters in the Neotropics and Asia. (Clark et al, 2015)

2.4 Environmental factors

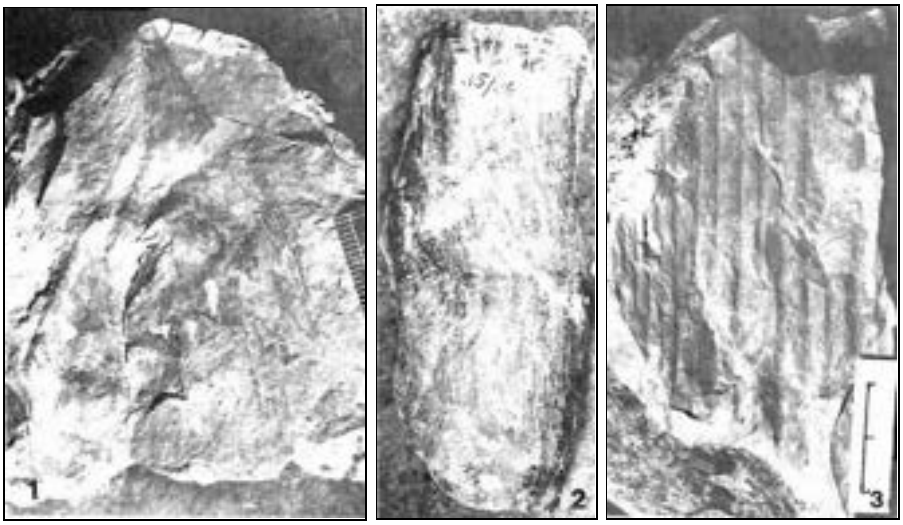
Bamboos plants can develop in most climates. Most are situated in tropical regions and just a few types can resist light frosts. This plant requires little care to survive, it can grow both with very little sun or in full sunlight, although in good conditions it can grow up to 2 inches daily. (Lewis, 2004). Bamboos prefer moist, fertile, free-draining soil (although they do tolerate most types). They can survive "in moderately poor soils but not constantly waterlogged or extremely dry conditions." (Royal Horticultural Society, 2022).

2.5 Fossil record

Despite their occupation in various habitats, the sensitivity to climate change, sporadic flowering and low rates of dispersal, contribute to bamboo's indigenous nature. In that sense, plate tectonics are also involved in their distribution across continents. Earliest fossils of bamboo have been reported in Asia, and their ancestors came from Gondwanaland which evolved in warm and humid environments. Fossil compressions/impressions of culms of *Bambusiculmus tirapensis* and *Bambusiculmus makumensis* dating back to the Oligocene age. Impressions of *Bambusium deomarense* and *Bambusium arunachalense* leaves found in northeastern India, date back to the late Miocene to Pliocene sediments. Culm fossils in this region provide the earliest evidence of bamboo from Asia, indicating that they spread across Asia from India post the establishment of land connections with the Indian and Euroasian plates. Neogene bamboos display the diversification of the plant's ecological niche during the Miocene age in Asia. These fossils also uncover their adaptation to monsoonal climate in the late Oligocene (Srivastava, 2018).

Figures 2.2 (*1*), 3 (*2*), and 4(*3*).

Two fragmentary leaf impressions and one culm impression (Srivastava, 2018).



The specimens presented can be described as *Bambusa* which was widely distributed across the Himalayan foothills from Himachal Pradesh to West Bengal between the Miocene and Pliocene. These fossils were located in the "left bank of the upstream of Ghish River and the right bank of Ramthi River near Oodlabari, Darjeeling District, West Bengal," (Srivastava, 2018).

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3.0 BIOLOGY

3.1 Chromosome complement

Most woody bamboos have a chromosome number 12 (x=12) while herbaceous bamboo has 11 (x=11). Woody bamboos present two different polyploidy groups. Tropical woody bamboos are hexaploids (*2n = 6x* = 72) and temperate woody bamboos are tetraploids (2n=4x=48) (Yeasmin et al, 2015).

3.2 Life cycle and phenology

3.2.1 Life cycle

As perennial flowering plants, bamboos have a life cycle that can be divided into three stages: the vegetative phase, mass synchronous flowering, and death. Numerous bamboo species stay in their vegetative phase for decades or a century. Seed plants experience similar life cycles: germination, juvenile stage, vegetative growth, reproduction (which includes flowering and formation of seeds). Bamboo is quite alike, yet it has its own flowering characteristics including: a long vegetative phase and the capability of asexual reproduction, with a single clone having the ability of populating an entire bamboo forest. Phenomena associated with flowering such as bamboo groves bursting into bloom and dying or sporadic flowering, has been recorded from more than 2,000 years ago to 1,721. “The book *Zhu Pu*, written by Dai during the Jin Dynasty (from 317 to 420) states: “Bamboo flowering and seeding needs 60 years and bamboo can regenerate through seed in 6 years,” (Zheng et al, 2020).

Bamboo flowering habits can be classified into four types: sporadic, massive synchronized, combined massive synchronized and sporadic, and partial flowering (Zheng et al, 2020).

3.2.1.1 Sporadic flowering

This type of flowering is defined as a random and irregular small number of flowering. Usually there are 1-2 clusters or a small area of spread bamboo flowering within a population. This type of flowering occurs randomly in cultivated or intensively managed species, although it rarely occurs in wild species. 53 bamboo species are reported to experience sporadic flowering (Zheng et al, 2020).

3.2.1.2 Massive synchronized flowering

Also known as gregarious flowering, covers a large flowering area of more than or 50% occurring within a bamboo population. Various plants exhibit cyclic patterns of gregarious flowering past a long vegetative period. 70 bamboo species have been reported to experience massive synchronized flowering. There is a great concern regarding this type of flowering given that it may lead to large-scale bamboo death that might affect local environments and economies (Zheng et al, 2020).

3.2.1.3 Combined massive synchronized and sporadic

In this type of flowering, bamboo might present sporadic or small areas of flowering prior and after large areas are subjected to flowering (Zheng et al, 2020).

3.2.1.4 Partial flowering

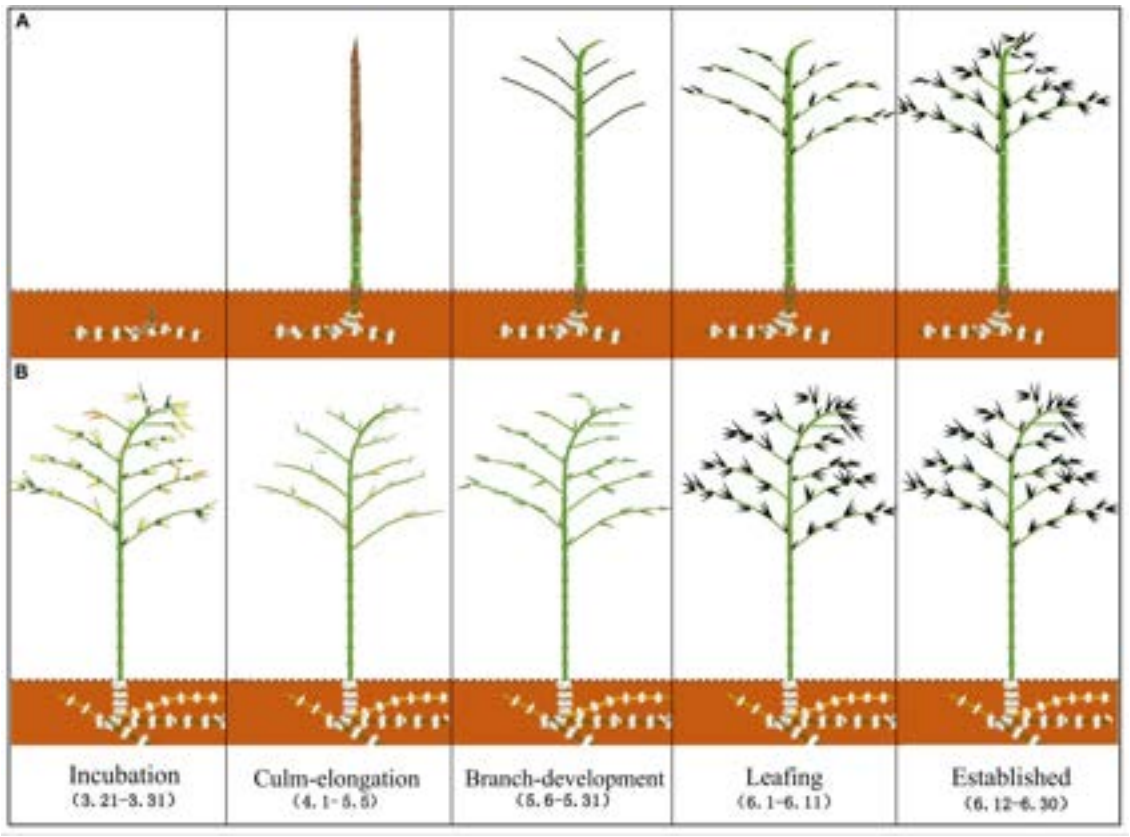
The degree of flowering in bamboo forests is between sporadic and massive synchronized flowering, typically in patched distributions (Zheng et al, 2020).

3.2.2 Phenology

Bamboo leafing phenology undergoes two stages within odd-year-old culms: sprouting and shedding. There are then five phases within both stages: incubation, culm-elongation, branch-development, leafing, and establishment. During incubation, shoots stay underground while leaves of odd-year-old culms stay on the branches but turn yellow. The second phase is when freshly sprouted culms grow above ground and reach their maximum height. The culms will then shed old leaves and flush new ones. In the third phase, freshly sprouted culms achieve their branch growth and new leaves expand on the odd-year-old established culms within the same period. During the leafing phase freshly sprouted culms flush leaves while the culms are almost done with leaf expansion. In the final establishment phase, freshly sprouted culms finish both their culm and leaf growth (Mei et al, 2020).

Figure 3.1.

"Phenological stages of (A) sprouting new culms and (B) leaf shedding and flushing on odd-year-old established culms," (Mei et al, 2020).



3.3 Anatomy and growth habits

3.3.1 Anatomy

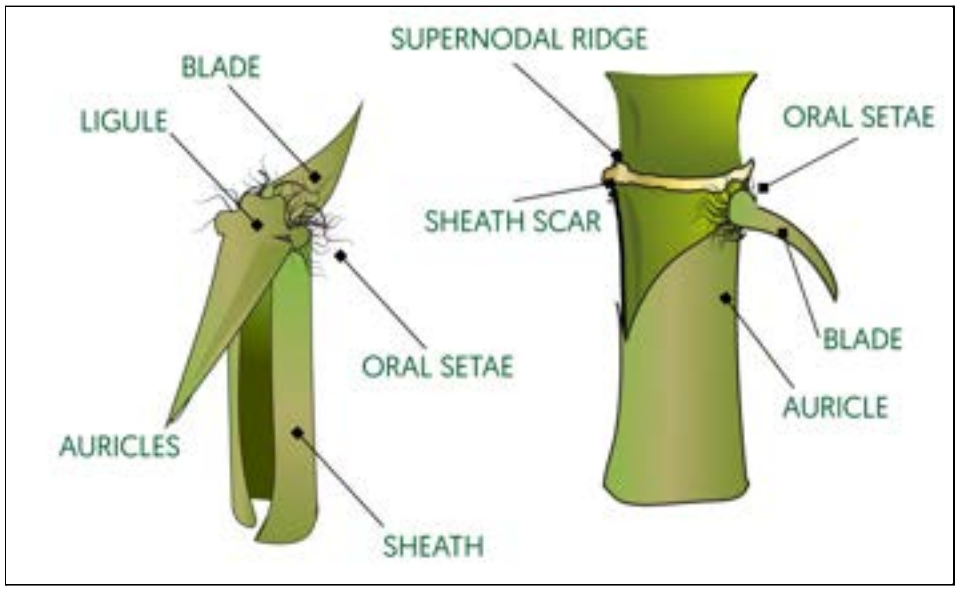
3.3.1.1 Shoot anatomy:

- **Sheath:** protective covering of the new growth in order to allow the bamboo time to harden and strengthen as the culm grows. Different colors, variegation, and pilose (furry) can be presented.
- **Blade:** lead like extension on the apex of the sheath which can present various forms.
- **Ligule:** inside projection of the blade which implements a seal to control water absorption and provide protection from pests.
- **Auricle:** small raised areas on each side of the ligule which assist its function (may not be present in all bamboo species).

- **Oral setae:** small hairs found on the auricles or that can be directly attached to the ligule (with the absence of auricles), (may not be present in all bamboo species).

Figure 3.2.

Bamboo shoot anatomy (Lewis Bamboo, 2022).

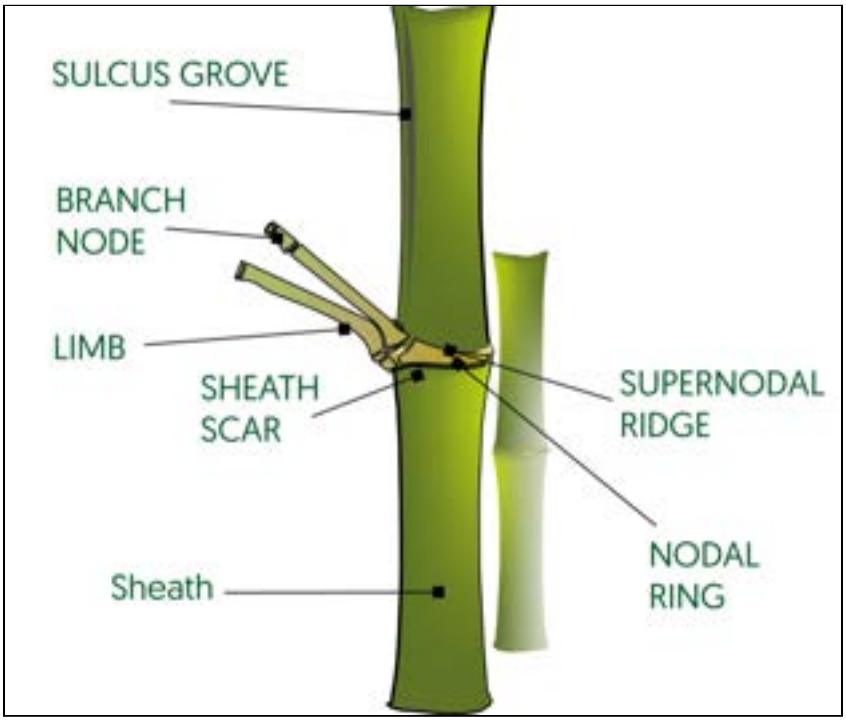


3.3.1.2 Culm anatomy:

- **Culm:** vertical vegetative axis of the bamboo plant.
- **Sulcus groove:** flat scar the limb formation leaves during the growth process (is not evident in all genus, yet it can be very pronounced in some).
- **Branch node:** nodal rings found in the branch formations that typically mimic nodal formations of the culm.
- **Limbs:** projecting growth from the culm that helps support the foliage. Limb count at the nodal ring serves to identify bamboo genus.
- **Supernodal ridge:** top ring at the nodal section of the plant (can present as subdued or pronounced).
- **Sheath scar:** lower ring at the nodal section of the plant which ranges in proportion based on the species. (Lewis Bamboo, 2022).

Figure 3.3

Bamboo culm anatomy (Lewis Bamboo, 2022).



3.3.1.3 Stem

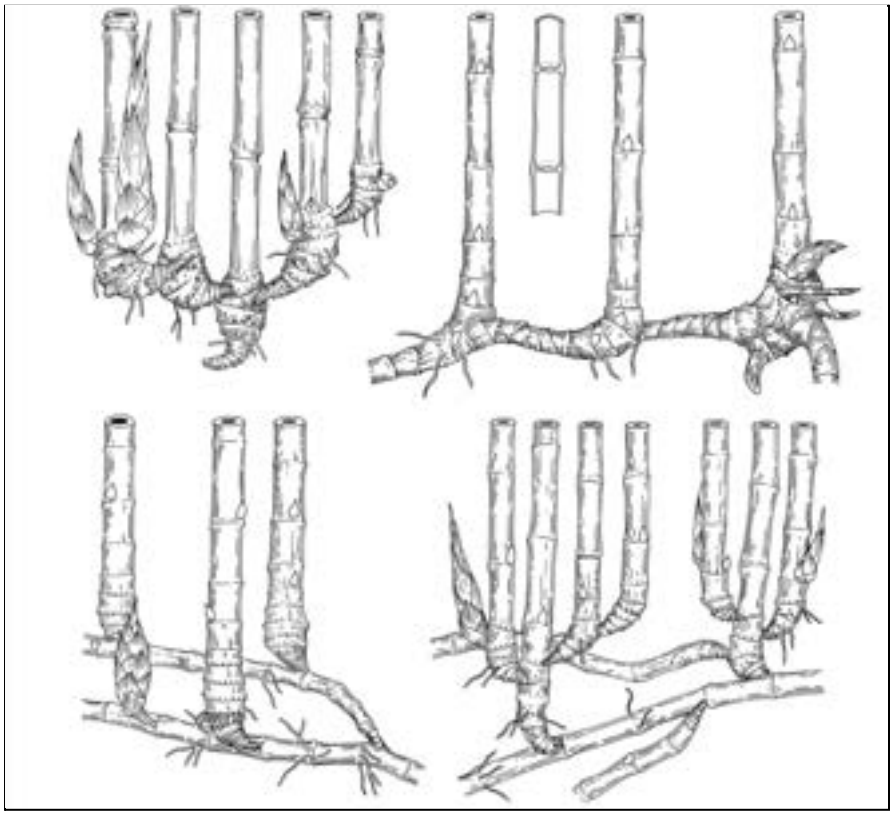
Otherwise known as the culm, it is the most visible part of the plant that develops from shoots emerging from buds (Akinlabi et al, 2017). The underground part of the bamboo stem is called the rhizome. The emergent part of the stem is called the culm. The rhizome, culm, and the branches are segmented. Segments are separated with nodes, there are also intervals between the nodes called internodes**.** The internal space of the culm is compartmentalized into hollows by each node holding a transverse plate. The stem is cylinder shaped with cross walls fixed at regular intervals along the culm to give the plant its strength and flexibility. Not all species exhibit the same growth patterns, as some possess very thick culm walls that might result in the central hollow being inconspicuous or even absent. In addition, not all bamboos have erect culms. That is the case of forest bamboos in South Asia which have slender culms that twine around tree trunks and ascend during their growth period. It must be highlighted that not all rhizomes are hollow. Species with clumping growth habits and their culm bases almost touch, contain a solid, thickened, and relatively short, spindle shaped rhizome. Species with running

habits and the culms are spaced out from one another, tend to have slender and hollow rhizomes, like in erect culms. Verticils of shoot roots are developed on the nodes on the rhizomes or even at the basal portion of the culms. Clumping or running habits are directly related to rhizome growth behavior. Rhizomes that turn upwards to continue growing as a culm, bear new rhizomes which then upturn to become culms and bear even further "daughter rhizomes". Sympodial series of rhizomes, such as the ones described above, are formed by "wave-like successions of rhizomes that build up as repeating units, which are successively newer generation," (Wong, 2004). These systems constantly bear short, thickened spindle-shaped rhizomes that develop culms put closely together as distinct culms (Wong, 2004).

"Running" bamboos are identified as those with slender, hollow rhizomes which have horizontal growth and without upturning to form a culm. Buds that evolve along the rhizome tend to develop new rhizomes or form culms directly and well spaced out over a wider area. These rhizomes are distinguished as monopodial which form groves of single culms and not clumps. This type of bamboo genera is uncommon in the tropics and is seen mainly in temperate regions. It is rare to find bamboo with mixed conditions (monopodial and sympodial rhizomes within the same plant) (Wong, 2004).

Figure 3.4.

Rhizomal system of Bambusa spp. (Wong, 2004)



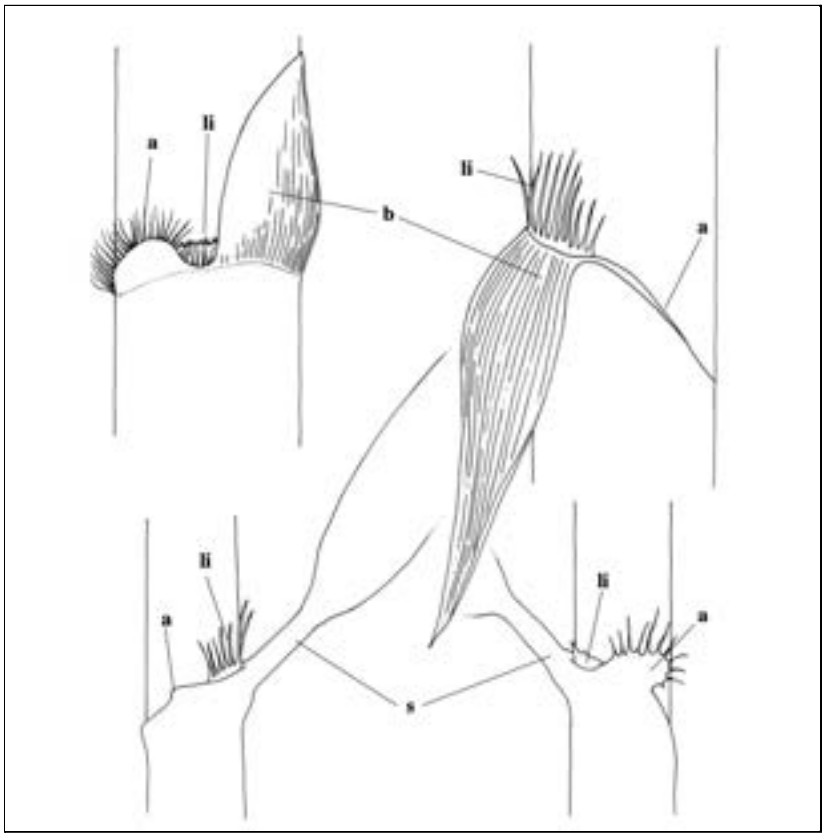
"A sympodial system with short rhizomes (top, left) has the culms close together, but long-necked sympodial rhizome units (top, right) carry the culms more apart, like those arising from monopodial rhizomes (bottom, left); a mixed or "amphipodial" system (bottom, right) has both sympodial and monopodial portions. Cut-away view of a culm shows internal spaces separated by crosswalls or diaphragms at the nodes," (Wong, 2004).

3.3.1.5 Sheath

Several types of sheaths dependent on the sheath organ emerging from the bamboo's node can be developed like: culm, leaf, branching, and rhizome sheaths. Although, the most apparent are the culm, which is a modified leaf comprising a blade, ligule, and auricles. The ligule is found within the inner part of the sheath where the blade connects. The auricle can be located on all sides of the blade base. Variations in culm sheath color, geometry, morphology, and placement in the nodal region are numerous. Certain species' sheaths might fall. Branch sheaths contain layers that closely encircle the branches growing from the nodal section of the culm. Sheath size is gradually reduced from the base of the culm or branch to the apex (Akinlabi et al, 2017).

Figure 3.5.

Culm and leaf sheathes of Bambusa spp. (Wong 2004)



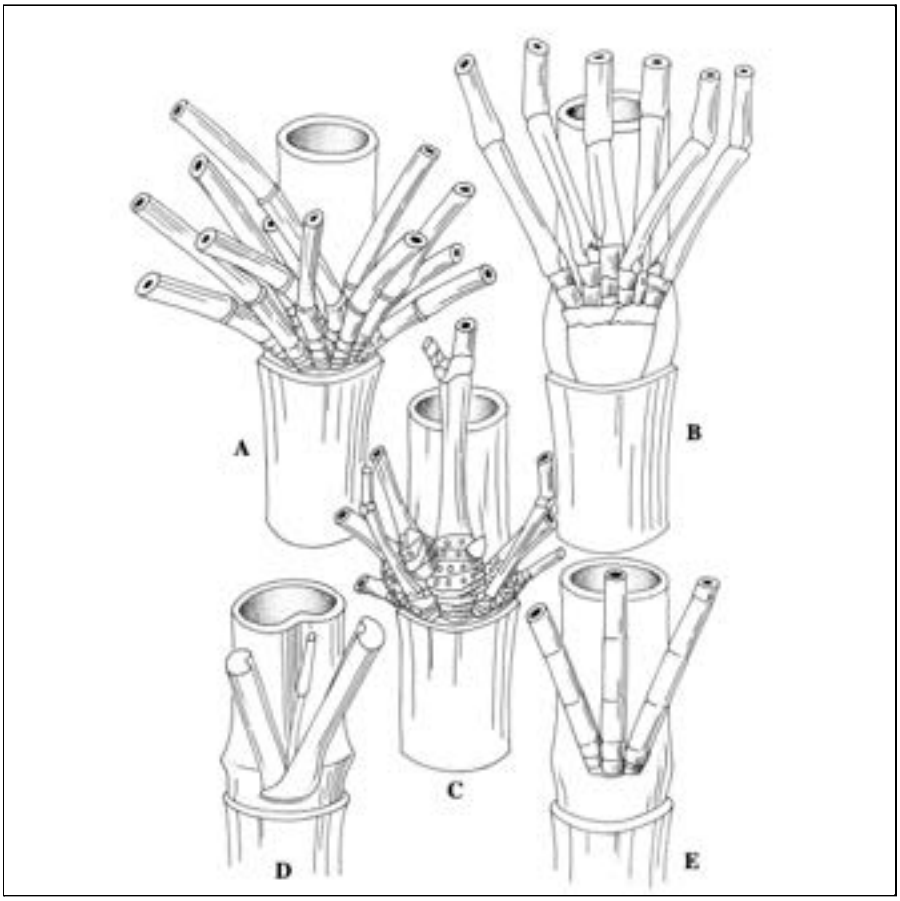
Culm sheaths (top) and leaf sheaths (bottom). A, auricle; b, blade; li, liguel; s, leaf or "stalk" (Wong, 2004).

3.3.1.6 Branches

Branches flourish from lateral sheath-covered buds that arise above the sheath scar from alternate sides of the culm. Branching can occur in syllepsis or prolepsis, meaning in the year when the culm comes up or the next. Primary dominant-stout branching and numerous subequal branching are the major types of branching within bamboo (Akinlabi et al, 2017).

Figure 3.6

Bamboo branch complements:



"many slender branches from many individual primary buds (A), many slender branches from a single primary bud (B), dominant primary branch and smaller branches proliferating from its base ©, pair of unequal main branches from one primary bud (D), three subequal main branches arising together (E)," (Wong, 2004).

3.3.1.7 Rhizomes

These subterranean organs or systems with multiple branching are in charge of the structure, stability, nutrient storage from photosynthesis, and territorial colonization. Each species' rhizome varys in appearance, color, and characteristics. Research has identified two types of rhizomes: pachymorph (sympodial) and leptomorph (monopodial) (Akinlabi et al, 2017).

3.3.1.8 Roots

The root systems allow the transportation and storage of nutrients, food, and water as well as guaranteeing structural anchoring. Bamboo roots are rather symmetrical in shape and

their diameters range from 0.4 to 4.8 mm in size. The roots are situated as a ring around the node region of the rhizome. Most of the rooting system can be seen within 330 mm of the soil's surface. Certain species' roots can stretch to depths of 700 mm below the surface (Akinlabi et al, 2017).

3.3.1.9 Leaves

Leaf blades differ from culm and branch sheaths as they are thinner, more dorsiventral, and have a petiolate (stalk). The leaf is an extension of the leaf sheath and the foliage due to its photosynthesis capability. The leaf organ also creates cauline leaves. "Morphologically, the leaves exhibit parallel venation," (Akinlabi et al, 2017). Most bamboo species experience dimorphism. Factors such as moisture of the content cultivating soil, location of the leaf on the branch, and age contribute to the plant's seasonal changes (Akinlabi et al, 2017).

3.3.1.10 Flowers

Each flower in a bamboo plant is confined by the attendant lemma which is a tiny side-branch of the rachilla. The palea[12] which has its back against the rachilla, embraces the whole flower. "Distal to the palea and wholly enclosed by it, the floral axis typically bears three smaller membranous structures called lodicules (comparable to the perianth, or sepals and petals, of an ordinary flower), stamens, and a female complement comprising the ovary and its style and stigma(s)," (Wong, 2004). A flower is labeled as "perfect" when it possesses both male (stamens) and female (ovary style structure) parts within the palea. The flower is denominated "empty" or "vestigial" when these structures are not built within the palea (Wong, 2004).

3.3.1.11 Fruits

Bamboo fruits are dry one-seeded structures that do not split when ripe, otherwise known as caryopsis. In generas like *Cyrtochloa*, *Dinochloa*, *Melocalamus*, *Melocanna* and *Sphaerobambos* fruits are fleshy, spherical, and can reach the size of a plum. In certain fleshy-fruited bamboos seeds germinate viviparously[13] (Wong, 2004).

[12] Palea: membranous structure with two inflexed edges.
[13] Viviparously: when the fruit is still attached to the parent plant.

3.3.2 Growth habits

New culms are produced during the spring. The shoots come out of the ground and take around 60 days to grow in height and diameter as well as producing limbs and leaves. After this period the canes stop growing, meaning that they don't experience secondary growth, although they will put on new foliage annually and live up to 10 years. Since bamboo is a colony plant[14]new shoots can emerge to turn into a culm with leaves and limbs during the 60 day period. Bamboo takes about 3 years to get established, then new shoots emerging during the spring continue to grow in size and number as the colony reaches maturity. Reaching maximum size is dependent on the species, soil, sunlight, climate and watering conditions, however, it takes on average 4 to 15 years for most species (Lewis Bamboo, 2022).

Most of the colony is grown underground which is equivalent to 50% of the plant's mass. Culms serve as nourishment for the underground colony of rhizomes. The increase of rhizome growth enables nutrient storage and the production of larger plants until a mature sized culm is obtained. New growing culms emerging upwards from rhizome nodes are very tender and fragile. Culms will emerge from the ground with a diameter that will be conserved throughout its whole lifespan and that will grow quickly for 40-60 days. Its growth rate has been measured at 4 feet during 24 hour for the spring shooting period. When the new shoot gets to its maximum height branches and new leaves unfold. It takes about 3 years in the ground before the bamboo mother plant begins producing multiple shoots to provide a grove appearance. A *Phyllostachys* species of 3 gallons should have a few new shoots during its first spring. The following spring, the canes can generate a few more canes each. By the third spring compounding growth will be evidenced as the canes produce even more growth of larger and taller stems than the years prior (Lewis Bamboo, 2022).

3.4 Reproductive biology

There are two propagation methods for bamboo plants, sexual and asexual. The first one is done throughout the use of seeds, although not all bamboo species produce them, and those that do are **sporadic** as they might take 30-120 years to flower, resulting in the death of the parent plant. Parents tend to die most of the time after flowering. Just a few species of bamboo

[14] Colony plant: uses energy from the already existing plant to produce more plants and expand the root structure.

flower frequently in order to produce seeds which can also be used to propagate with seedlings. Bamboo seeds have a short lifespan preventing its preservation for longer periods (Akinlabi et al, 2017).

The second propagation method applies to those species that do not flower and produce seeds for the regeneration of seedlings that are propagated with vegetative techniques like stem cuttings or non-clump species' rhizomes.

Bamboo seedlings are a better suited method of propagation for large plantations as clumps produced from seeds maintain their "genetic originality (ancestral roots)" (Akinlabi et al, 2017). Maximum quality culms are produced from clump bamboos originally propagated using seeds, as the clumps will have a longer lifespan on the plantation. "However, one characteristic of bamboo before seeds are produced is that the clumps die off after flowering," (Akinlabi et al, 2017). After the production of seeds they have a short-lived viability, thus, they should not be reserved for long periods of time.

Asexual propagation tends to use such parts like the rhizome, offset, or culm cuttings which are transported to a nursery for the regeneration of new shoots. "The formation of new shoots from these propagules is allowed to mature and develop new rhizomes before being transferred to their permanent place of cultivation. The types of vegetative propagation methods include offset planting, rhizome planting, culm cut planting, split culm cuttings, branch cuttings, layering, marcotting, and macro proliferation of seedlings," (Akinlabi et al, 2017).

3.5 Pests and diseases

It is recommended to have a systematic control of parasites, insects, or grazing animals in bamboo environments during their early stages of development. In areas where animals are prone to invade plantations, there must be serious protection of seedlings to prevent animal's access to farms and guarantee the seedlings' quality of growth. Fencing methods are appropriate for smaller plantations. For commercial farming close supervision is recommended to prevent grazing as larger fencing areas are rather expensive for the longer duration bamboo seedlings take to mature into culms. To monitor defects or outbreaks caused by insects or animals within the plantation, the farm must be patrolled in full length and breadth, checking each plant for any possible damage to find the remedies necessary (Akinlabi et al, 2017).

Bamboo is rarely threatened by pests and insects in plantations. However, when it is attacked by such organisms, it is easily controlled with pesticides and insecticides with high concentrations of glyphosate (about 41%) in case of an outbreak (Judy and Williamson, 2021). Untreated plants might face hindered growth and quality of culms.

The most common problems bamboos might encounter are: rust disease, root rots, and bamboo aphids. Rust disease is a common fungal disease of herbaceous plants, these tend to be unsightly and might reduce plant vigor. In extreme cases it can kill the plant. Rusts affect aerial parts of the plant, most commonly on leaves, and occasionally on stems, flowers, and fruit. Spore pustules produced by the disease vary in color from orange, yellow, brown, black, or white, depending on the species and type of spore being produced. Rusts' life-cycles are complex as they can involve two different host plants and even five types of spore. **Phytophthora**[15] root rot "is the most common cause of root and stem base decay," (The Royal Horticultural Society, 2021). The organisms causing the root and stem base decay are found within the soil, where they can survive for various years without a host plant. This disease prevails in heavy or waterlogged soils. Some species can act as foliar pathogens and spread through air-borne spores. These spores swim in the water films between soil particles and can travel short distances on their own. However, chemicals from the roots of susceptible plants giving off into water films can attract spores toward them. Phytophthora can also produce long-lived resting spores which are liberated into the soil from decaying roots. These spores contaminate the soil in the proximity of an affected plant for quite some time or even for several years. Long-distance spread of the disease happens when the spores or the soil containing them is carried in drainage or run-off waters. Moving infested soils during cultivation or transplantation can spread the disease. Aphids are sap-sucking insects (**true bugs**) that "can cause lack of plant vigor, distorted growth", plant viruses, and growth of sooty molds due to the execution of honeydew. Aphids are otherwise recognized as greenfly or blackfly, there are other yellow, pink, white, or mottled species. Most species suck sap from the plant's foliage, stems, flowers, and even eat from their roots, their life-cycles are spent on more than one host plant. Several aphids feed on one or two plant species, although others can be found in a series of plant hosts (Akinlabi et al, 2017).

[15] Microscopic, fungus-like organisms.

Figure 3.7

Bamboo aphids found on bamboo plant, underside of leaf in Norfolk, Virginia (Justis, 2008).

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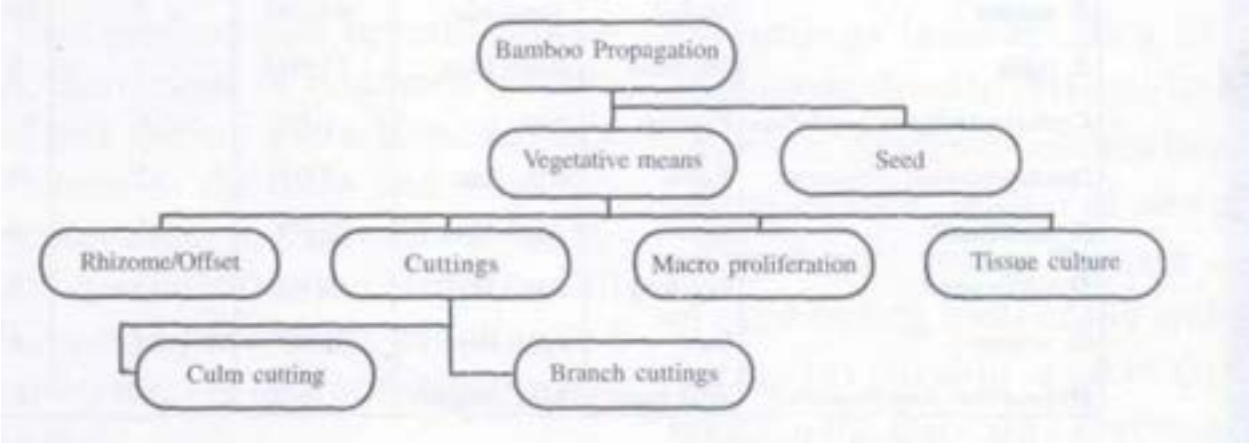
4.0 Production and propagation

This chapter concerns itself with the production and propagation of bamboo through vegetative means and through seed propagation. The majority of methods of propagation fall under vegetative means, Figure 1, below.

4.1 Conventional propagation

Figure 4.1

Division of types of bamboo propagation into seed and vegetative means (Ahlawat et al, 2002).



4.1.1 Seed

Planting fresh, mature seeds allows large numbers of new plants to be obtained. Most bamboo species germinate in a span of 5-10 days with a high germination percentage (CTAHR, 1997).

At a glance propagation through seedlings is as follows: “seed, sowing in nursery bed, transplanting to polybags, keep shade beds, transfer to open beds,” (Ahlawat et al, 2002).

4.1.2 Off-set planting

Off-set planting is recognized as an age-old vegetative propagation method and is the most common method used for the propagation of bamboo. It is practical in the cultivation of a few clumps in small and accessible areas, however, the availability of propagules in large quantities is limited through this method. Offsets propagate best if they are planted just before

the rainy season. The success of this method in thin walled species is relatively poor and varies from one species to the other. Species with large diameter culms need larger rhizomes for planting. The implementation of rhizomes for propagation purposes is limited to non clump forming (monopodial) species. “Off-set from 1-2 year old culms are cut at about 1.0-1.5 m height (3 to 5 nodes bearing viable branch buds), that is excavated along with a portion of rhizome with its root system,” (Ahlawat et al, 2002). The rhizome should be detached by cuttings from its neck causing minimal damage to the rhizome during excavation. Off sets are best removed and planted in the rest season before the rainy season in order for them to be capable of settling roots easily. Those removed during late rainy season after new growth begins tend to fail in their establishment. Offsets must undergo immediate transplantation after being extracted from their other clum and be stored in moist gunny bags during their transportation. To prevent drying in the field, the top cul should be covered with a polythene bag and a cavity filled with water. During prolonged dry weather, daily watering is needed. The steps taken to carry out this technique in short are: “identify healthy culms, select 1-2 year old culm, extent culm with basal rhizome, avoid damage to other culms, prepare planting stock with basal 3-5 nodes and rooted rhizomes, prepared large pits in planting sites, plant offsets/rhizomes with top portion covered by poly bags, water if needed. Avoid extraction in growing season,” (Ahlawat et al, 2002).

More effective techniques that meet larger demands of planting stock as the ones explained below, result in mass seedling production (Ahlawat et al, 2002).

4.2 Non-conventional propagation

4.2.1 Macro proliferation

This method is performed in small seedlings typically raised through seeds. Macro-proliferation is known as the propagation of bamboo seedlings by rhizome separation that drives to smaller sized planting material. 5-9 month old seedlings are increased 3-5 times every year. Bamboo seedlings expose rhizome development in 30-40 days when it also generates culms. Seedlings with 4-5 culms are removed from their beds, and then the soil is taken out from them through washing or shaking. Each culm with a chunk of rhizome and roots is cautiously separated with a sharp knife and planted in individual poly-pots as seedlings. New culms will be produced when these undergo proper nursery conditions. This process can be repeated and can perennially make a good stock of plantable seeds. At a glance the steps taken for this method of

propagation are: “raise seed raised seedlings 5-9 month old with 4-5 culms, separate each culm with roots and rhizomes attached, transplant to individual poly bags, keep in shade, water regularly, repeat process when seedlings ready or use for plantation,” (Ahlawat et al, 2002).

4.2.2 Culm cutting

As a vegetitive method, it is a viable alternative and is more advantageous than other methods of propagation. Success and survival rates are higher from 40 to 80% in comparison to the offset method. This procedure involves treating culm cuttings with growth regulating chemicals for inducting root development. Culm cutting has been reported as a successful method within most bamboo species that uphold economical importance. Broad scale propagation of superior varieties is possible throughout culm cutting. Bamboos raised from cuttings have a quicker evolution than seedlings. At a glance the steps performed for this vegetative propagation are as follows: “select 1-2 year old culm, extract culm, remove top portion of culm and trim lateral branches, cut into 2 nodded segments, make a hold in the internode, pour boric acid solution, cover the hole, plant horizontally in raised nursery beds, water regularly, protect sprouts, separate rooted seedlings, and plants will finally be ready for planting,” (Ahlawat et al, 2002).

4.2.3 Branch cutting

Several thick walled species generate stout branches containing basal nodes of branches with root primordia. The branches are then chopped and cautiously extracted from 1-3 year old culms. 3-4 nodded cuttings are arranged from these branches and then “planted in to propagation beds obliquely vertical,” (Ahlawat et al, 2002). The cut portion is sealed with molten wax, however, treatments of rooting hormones such as IB A, NAA or other commercial preparations might grant better results. Mist chambers also serve for cuttings’ better propagation, these are buried 7-10 cm in sand bed mist chambers. Sprouting and rooting will occur in 1-4 months and can later be transplanted to poly pots conserved in shade beds at first and then the seedlings can be placed in open beds. The seedlings will then be ready for plantation. Branch cutting is a more common, economical, and effective method of propagation. This propagation follows these steps at a glance: “select good culms of thick walled bamboos, extract basal lateral branches, with root primordial, cut into 2-3 nodded segments, dip in hormone solution, plant in sand beds in mist

chamber, seel exposed cut ends, transplant rooted sprouted branch segments to poly bags, keep in shade, after 6 months they will be ready for planting," (Ahlawat et al, 2002).

4.2.4 Layering and marcotting

This method involves three types of layering procedures: ground or simple, air, or macotting and stump layering. In the first, a 1 year old culm is pruned avoiding injury to dormant buds and then buried halfway under well prepared soil so the buds along each side of the culm remain in lateral position. Aerial or ground rooting can be induced in certain bamboo species by detasseling of the shoot top and extracting newly emerging culms from the clump. Air and ground layering have been reported 28% successful mainly in mid-culm zones, yet it varies from one species to the other. In the marcotting procedure a 1 year old culm is bent so all its nodes are within easy reach of the worker. The branches of the nodes are then pruned 2.5-4 cm from the node. "An admixture of garden soil, leaf mould and rootex, Rootone or any other commercial rooting hormone preparation is placed around each node and longitudinally wrapped with coconut fiber or water hyacinth roots," (Ahlawat et al, 2002). It is then securely tied at both ends. Rooted nodes are detached from the stem to grow into a new plant containing its own roots and planted in the field. The following steps are fulfilled in this process at a glance: "1 year old culm, prune the branches, half bury under soil media. For marcotting place mixture of garden soil, leaf mould and rooting hormone at each node, wrap with coconut fibre and polythene, rooted nodes separated, new plants planted in field," (Ahlawat et al, 2002).

4.3 Management

Bamboo is usually implemented for ornamental accents in gardens. These species range in size and invasive potential, mostly those that belong to "running" bamboo and spread aggressively through a network of roots and rhizomes. On the other hand, "clumping" species are less aggressive and invasive as they spread slowly. The rhizome network serves as an energy and storage mechanism, thus all rhizomes must be exhausted to eradicate bamboo from the landscape. Several species have astounding growth rates, as quick as 4 feet in 24 hour periods. This rate is tempting when establishing a hedge or a screen, although invasive species might turn troublesome when a screen is settled. Maintenance programs performing routinely mowing or cutting shoots emerging outside of the desired location of the bamboo plantation should be

considered. Once entrenched, it is very labor-intensive to eliminate bamboo from an area. Strategies like mechanical removal of all stems and roots are the most effective for achieving this purpose. Heavy machinery is sometimes required with root system removal as it is often difficult. Another option is to remove the bamboo's stems to ground level and start an intensive mowing program that guarantees the removal of re-sprouting foliage. However, mowing must happen constantly for months or even years "...to exhaust the extensive rhizome network's resources," (Fite, n.d.). Herbicides are usually recommended, yet they are unsuccessful at eliminating bamboo by themselves (Fite, n.d.). Non-selective herbicides with active glyphosate are the best alternative as it possesses little residual soil activity and only kills plants that directly contact it. The effectiveness of glyphosate is given when bamboo is mowed or chopped and allowed to regrow until the expansion of new leaves. One application of this herbicide will not be enough to get rid of bamboo, it might take two to three years to establish complete control (Judy and Williamson, 2021).

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5.0 PRODUCTS AND MARKETING

5.1 World trade

2.5 billion people around the world have an economical dependence on bamboo as expressed by the INBAR in 1999. International trade of this plant species amounts to $2.5 millions USD according to an INBAR report from 2005. India, China, and Japan are the three main countries where bamboo is an important economic asset. By 2004, China's bamboo industry created a value of $5.5 billion USD. From 2000 to 2004 the bamboo-based GDP increased by 120% and export earnings grew 20% reaching $600 million USD (Lobovikov et al, 2007).

INBAR's report for the annual export of bamboo during the year 2000 was given a value of $2.5 billion USD. The main producers and exporters of bamboo in Asia were China, Indonesia, and Vietnam. $25 millions USD worth of raw bamboo were exported by China (⅓ of the total world deal), $10.6 million USD by Indonesia (12%), and $7.7 million USD by Vietnam (8.6%). $89 million USD constitutes the total value of exported raw bamboo. Singapore and Hong Kong lie within top bamboo and rattan processing centers and exporters. $18.6 million USD accounted for the trade of bamboo raw materials in Singapore (20.9% overall world trade). On the other hand, Hong Kong accounted for $4.69 million USD (5.3% of the world total) (Lobovikov et al, 2007).

Despite serving multiple small users around the world, international trade statistics reveal that it has turned into a very competitive resource internationally. The promotion of small, medium, and large scale industries would facilitate poverty reduction and sustainable development in both economic and environmental sectors. The implementation of modern techniques and technology allow various processes to transform bamboo into a menagerie of commodities. Engineered bamboo is a strong competitor in highly demanding international markets for wood and other raw materials (Lobovikov et al, 2007).

Table 5.1.

Exports of bamboo products by continent as of the year 2000.

Export of bamboo products in 2000 (*million US$*)

	Africa	Asia	Europe	North and Central America	Oceania	South America	Total
Bamboo products	29	1 554	739	120	8	5	2 455
Market share %	1.2	63.3	30.0	4.9	0.4	0.2	100.0

Table 5.2.

Main importing countries of bamboo as of the year 2000.

Main importers of bamboo products in 2000 (*million US$*)

	USA	UK	Netherlands	Germany	France	Japan	Hong Kong	Others	Total
Bamboo import	899	125	106	169	169	349	163	475	2 455
Market share %	36.6	5	4.3	6.9	6.9	14.2	6.6	19.3	100.0

80% of the world's bamboo imports are constituted by the main importers together. 71% of the total market share of major markets for bamboo products is the total of The European Union, Hong Kong, Japan, and the United States.

5.2 Potential bamboo markets

The usage of bamboo in the United States is viewed as a complementary crop that serves either for niche markets, farms or as a primary cash crop. There are three main uses for bamboo: domestic, commercial production, and ornamental, landscape, and conservation. The first use includes vegetable stakes, trellis poles, and shade laths implemented within the farming industry. The second use is seen in construction, food, and the arts in the forms of concrete reinforcement, fishing poles, furniture, crafts, edible shoots, or musical instruments. The third use can be observed in specimen plants, screens, hedges, or riparian buffer zones (Diver, 2001).

Bamboo canes used for strength and durability purposes (furniture, flutes, crafts, fencing) should be harvested between their third to fifth year of age. Before the end of year three, cane tissue still contains comparatively soft sap. Therefore, marking and selecting canes is part of the growing management. Canes implemented for utilitarian purposes around the farm do not need any specific conditions, they can be used as soon as they are available (Diver, 2001).

5.2.1 Plant material

Soil conditioning

In degraded mined lands of China and India, bamboo propagation is used for soil-nutrient reclamation and rehabilitation. Bamboo is suitable for rehabilitation purposes as it binds loose

soils to impede erosion. It is also very versatile as it develops in a variety of soils with poor mineral and nutrient content.

5.2.2 Food and medicine

Bamboo shoots are known to have high nutritional value in fibers, proteins, vitamins, minerals, carbohydrates, amino acids, and low fat, thus giving it a wide potential as both food and medicine. Bamboo forms an essential part in the traditional cuisines of Asian and African countries like China, India, Tanzania, Uganda, Ghana, and others. Young bamboo shoots contain phytosterols which bring a youthful feeling, healthy dynamism, and longevity to consumers that constantly refer to it as medicine. Significant amounts of vitamin A, vitamin B6, vitamin E, niacin, and thiamine can be found in freshly harvested shoots. These are filled with dietary fiber and carry few levels of cholesterol and phytosterol, therefore, labeling it as a natural health food (Akinlabi et al, 2017).

5.2.3 Construction material

The culm serves as an alternative to wood in the construction industry as it is dynamic and suitable given its economic and ecological advantages. The mechanical properties of bamboo culms increase in thickness of fiber walls and are appropriate as well for load-bearing structures (they can also work for non-load-bearing structures). For safety reasons and life expansion, bamboo and its derivatives must be treated with preservatives because it is very vulnerable. Less significant safety procedures are performed when the bamboo culms are used indoors, yet it is still important to employ preservatives against mold, mildew, fungus growth, and destructive insects, especially in tropical and subtropical areas (Akinlabi et al, 2017).

5.2.4 Musical instruments

For centuries, natural bamboo culms have been manufactured for musical instruments. The culm can have various applications for wind, percussion, cord instruments, and the cords itself. Many ethnic groups' music is characterized by the sound made by the hollowed structure of the culm. To produce an excellent flute, just a few finger holes and a mouthpiece are needed. In xylophone-like instruments, the lengths of the culms are used as resonators below the bronze keys (Akinlabi et al, 2017).

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