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An Overview of Bamboo Biodiversity: Exploring their Genetic Resources, Sustainability and Uses: Review Article

Achugbu Adaeze Nnedinma*[1], Odiah Veralyn Ummi[1], Okolie Henry[2] and Okoubulu Ben Augustine[3]

[1]**Department of Botany, Faculty of Biosciences, Nnamdi Azikiwe University, Awka**
[2]**Department of Crop Science and Horticulture, Faculty of Agriculture, Nnamdi Azikiwe University, Awka, Nigeria**
[3]**Department of Materials and Metallurgical Engineering, Southern Delta University, Ozoro, Delta State, Nigeria**
***Corresponding author's email: an.achugbu@unizik.edu.ng**

ABSTRACT

Bamboo plant is native to Southeast Asia, Africa, and Americas. Bamboo is a member of family Poacaceae (Graminae). There are approximately 70 genera making up over 1200 species. Bamboos belonging to family Poaceae are considered as one of the most versatile multi-utility forest species. The applicability of bamboo is highly diverse as they are employed immensely in paper, handicraft industry, house construction, and making furniture, water pipes, storage vessels and other important household items. Bamboo's rapid growth, durability, and renewability make it a valuable resource for various industries, promoting sustainable practices and reducing environmental impact. Edible bamboo shoots have immense potential of being used as important health food as they contain high proteins, amino acids, carbohydrates, many important minerals, and vitamins. Freshly collected bamboo shoots have good amount of thiamine, niacin, vitamin A, vitamin B6, and vitamin E. Bamboo sequesters carbon better than terrestrial forests. It can sequester up to 17 tonnes per hectare per year of atmospheric carbon dioxide within the roots systems. Bamboo provides tremendous restorative powers to degraded lands, clean soil and water of contaminants, mitigate erosion especially along water shades, restore moisture content and revitalize soil nutrients. Understanding the bamboo genetic diversity, multiplication techniques, growth potentials and produce utilization is crucial for harnessing its full potential and promoting sustainable development practices.

Keywords: Bamboo, biodiversity, genetic diversity, multi-utility, environment restoration.

INTRODUCTION

Bamboo plant is native to Southeast Asia, Africa, and Americas. This popular plant is used in many purposes such as ways from constructing of housing, food and medicine. Bamboo is a member of family Poacaceae (Graminae). There are approximately 70 genera making up over 1200 species. Bamboos belonging to family Poaceae are considered as one of the most versatile multi-utility forest tree grasses. The applicability of bamboo is highly diverse as they are employed immensely in paper, handicraft industry, house construction, and making furniture, water pipes, storage vessels and other important household items [1]. "Bamboo sequesters carbon better than terrestrial forests. It can sequester up to 17 tonnes per hectare per year within the roots systems [2]. Bamboo provides tremendous restorative powers to degraded lands, clean soil and water of contaminants, mitigate erosion, restore moisture content and revitalize soil nutrients [2]. People from different countries address bamboos in different names because of their highly multipurpose properties. The Chinese called bamboos as "Friends of the people," Vietnamese as "My brother," and Indians as "Green Gold." Bamboos in addition to their multiple applications have another important usage in utilizing their juvenile shoots as popular food items [3]. Bamboo shoots have immense potential of being used as important health food as they contain high proteins, amino acids, carbohydrates, many important minerals, and vitamins. Freshly collected bamboo shoots have good amount of thiamine, niacin, vitamin A, vitamin B6, and vitamin E [2]. Non-wood forest products are known to generate substantial foreign exchange and are increasingly being regarded as valuable commodities around the world. Our perception and evaluation of non-wood forest

products is changing due to alarming rates of deforestation and decreased timber yields [4]. One of the key reasons for the importance of bamboo is its rapid growth rate. Bamboo is known to be one of the fastest-growing plants in the world, with some species growing as much as 91 cm (35 inches) in a day for species like *Phyllostachys edulis* but on the average, bamboo species grow up to 10 cm (4 inches) per day [5]. This rapid growth makes bamboo an easily renewable resource that can be harvested without causing harm to the environment [5]. In addition to its fast growth rate, bamboo is also incredibly strong and durable. Bamboo has a higher tensile strength than steel, making it an ideal material for construction and furniture. Its flexibility and lightweight nature also make it a popular choice for a wide range of applications. Furthermore, bamboo plays a crucial role in environmental conservation. Its rapid growth, strength, and eco-friendly properties make it a valuable resource for various industries and a vital component in the fight against climate change. Bamboo is a diverse plant species that encompasses over 1,400 different varieties, each with its unique characteristics and uses. These species are distributed across various continents, with the majority found in Asia, particularly in countries like China, India, and Thailand. However, bamboo can also be found in regions of Africa, South America, and Australia. Some of the most known bamboo species include Moso bamboo (*Phyllostachys edulis)*, which is native to China and known for its fast growth and large size. Another popular species is the Golden bamboo (*Phyllostachys aurea)*, prized for its golden-colored culms and ornamental value. Other notable bamboo species include *Bambusa vulgaris*, *Dendrocalamus giganteus*, and *Gigantochloa atroviolacea*, each with its unique characteristics and uses [6]. The distribution of bamboo species is largely influenced by environmental factors such as temperature, rainfall, and soil conditions. Bamboo thrives in tropical and subtropical climates, where it can grow rapidly and spread across vast areas. It is often found in dense forests, along riverbanks, and in mountainous regions, where it provides a valuable habitat for various wildlife species. Bamboo offers a range of both ecological and economic benefits, making it a valuable resource for various industries and environmental conservation efforts. Ecologically, bamboo plays a crucial role in preserving the environment. Bamboo plants have deep root systems that help prevent soil erosion and promote water conservation by stabilizing soil and reducing runoff. Additionally, bamboo forests provide habitat and food sources for various wildlife species, contributing to biodiversity conservation. Due to its fast growth rate and efficient carbon sequestration properties, bamboo also helps in mitigating climate change by absorbing carbon dioxide and releasing oxygen into the atmosphere [7]. Furthermore, bamboo cultivation can have significant economic benefits for local communities and economies. Bamboo is a versatile plant that can be used for various purposes, including construction materials, furniture, textiles, and food. This diversity of uses creates numerous economic opportunities for farmers, artisans, and entrepreneurs involved in the bamboo industry. In addition, the rapid growth and regenerative properties of bamboo make it a sustainable and renewable resource that can generate income for communities while promoting eco-friendly practices [8]. The ecological and economic benefits of bamboo make it a valuable resource for sustainable development and environmental conservation efforts. By harnessing the potential of bamboo cultivation and utilization, we can create a more environmentally friendly and economically prosperous future. Sustainable bamboo propagation is essential for maintaining the long-term health and abundance of bamboo forests, as well as for supporting the livelihoods of people who depend on bamboo for various purposes. Sustainable bamboo cultivation practices help to ensure that bamboo resources are managed responsibly, allowing for continued growth and use without depleting the resource or harming the environment. Sustainable bamboo propagation is important for biodiversity conservation, as bamboo forests provide habitat for various wildlife species and play a crucial role in maintaining ecosystem balance. By adopting sustainable cultivation methods, such as selective harvesting and reforestation, we can protect the biodiversity of bamboo forests and preserve the natural habitats of many plant and animal species [9]. Other animals besides lemurs and panda are dependent on bamboo. There is a community of rainforest organisms that rely on so-called bamboo wells, cavities in fallen bamboo culms that fill with rainwater. Additionally, sustainable bamboo propagation supports local economies by providing opportunities for income generation and livelihood enhancement. Sustainable bamboo propagation is essential for preserving the ecological, economic, and social benefits that bamboo forests provide. By promoting responsible management and cultivation of bamboo resources, we can ensure the continued availability of this valuable plant for generations to come.

ORIGIN AND DISTRIBUTION

Bamboo plant is native to Southeast Asia, Africa, and Americas. Bamboo is a member of family Poacaceae (Graminae). There are approximately 70 genera making up over 1200 species. More than 1642 species of bamboo have been recorded [10]. The species are distributed mainly across Asia, Africa and South and Central America. Fewer than one hundred are cultivated in significant quantities. These species are distributed across various continents, with the majority found in Asia, particularly in countries like China, India, and Thailand. However, bamboo can also be found in regions of Africa, South America, and Australia. Some of the most known bamboo species include Moso bamboo (*Phyllostachys edulis)*, which is native to China and known for its fast growth and large

size. Another popular species is the Golden bamboo (*Phyllostachys aurea)*, prized for its golden-colored culms and ornamental value. Other notable bamboo species include *Bambusa vulgaris*, *Dendrocalamus giganteus*, and *Gigantochloa atroviolacea*, each with its unique characteristics and uses [6]. The distribution of bamboo species is largely influenced by environmental factors such as temperature, rainfall, and soil conditions. Bamboo thrives in tropical and subtropical climates, where it can grow rapidly and spread across vast areas. It is often found in dense forests, along riverbanks, and in mountainous regions, where it provides a valuable habitat for various wildlife species.

BOTANICAL DESCRIPTION

Bamboo grows faster than any other plant on earth. It is the longest grass in the world, varying in length from 30 centimeters to as high as 40 meters. Bamboo lasts from 20-50 years. On the average.it grows up to 10 centimeters a day. Bamboo grows so fast you can watch it grow. Bamboo plants have deep root systems that help prevent soil erosion and contribute to watershed protection.

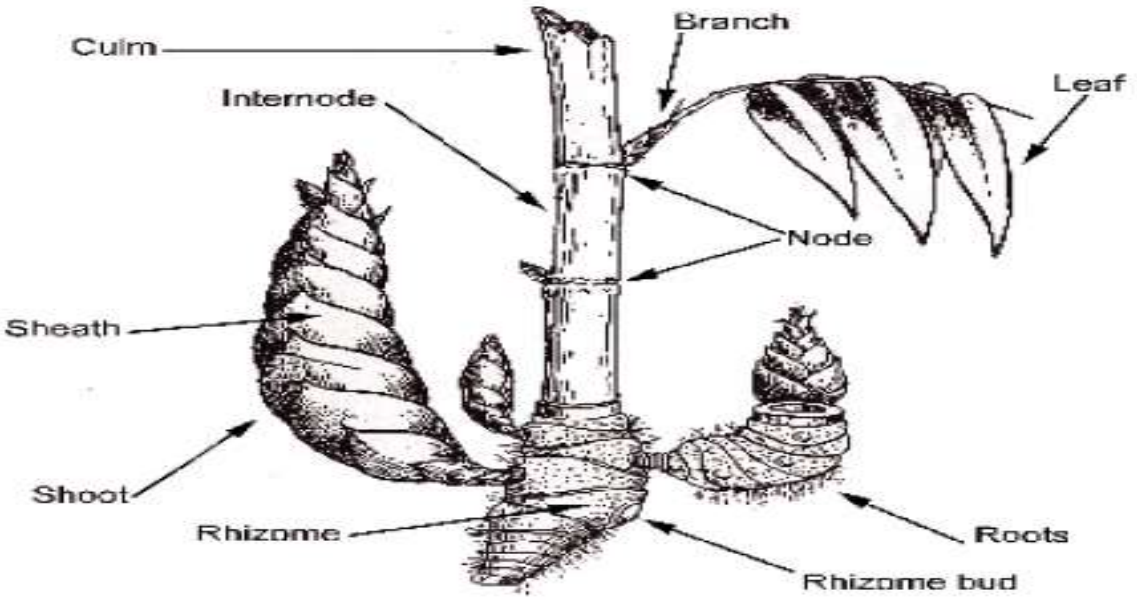

Fig1: Bamboo branch [11]

Additionally, bamboo absorbs carbon dioxide and releases oxygen into the atmosphere, making it a valuable tool in combating climate change [12]. Overall, bamboo is a versatile and sustainable plant that offers a wide range of benefits to both humans and the environment. Bamboo controls soil erosion and stabilizes riverbanks. It grows in most places in the world (except Antarctica) even under adverse conditions. In a lifespan of 35 years, a bamboo plant can produce 15 kilometers of usable pole. The bamboo plant consists of: An underground axis, and above ground axis. The underground axis consists of rhizomes, roots and buds. The above ground axis consists of stems, branches, and foliage. Buds on the rhizomes may develop into shoots that emerge from the ground. The new shoot elongates vertically into a main stem or culm until it attains its full height of between 8m -15m. The bamboo culm is cylindrical and is divided into sections by nodes. The section between two nodes is called an internode [11]. Internodes are hollow in most bamboos, but solid in some species for example *Oxytenanthera abyssinica*. The new culm is protected by sheaths that are attached to each node. The culm gradually develops branches and leaves. As the culm matures, it lignifies and becomes harder and stronger. The life of a culm varies from species to species. Under ideal conditions a culm is fully mature after 3 or 4 years. As mature culms grow older, they deteriorate and eventually die and rot. The life of the bamboo plant is however sustained by the new shoots and culms through their extensive rhizome systems. Bamboos are classified according to the two main rooting (rhizome) systems namely; Clump forming rhizomes otherwise called sympodial branching pattern and a running or creeping pattern otherwise called monopodial system [11].

Properties of Bamboo

Bamboo possesses some properties which makes it suitable for constructional work. The properties of bamboo are discussed below.

a. Chemical Property: The main constituents of bamboo culms are cellulose and lignin. Higher benzene-ethanol extractives of some bamboo species is an advantage for decay resistance [13]. The ash content of bamboo is made up of inorganic minerals primarily silica, calcium, potassium, manganese and magnesium. Silica content is higher in the epidermis with very little in the nodes and is absent in the internodes. Higher ash content in some bamboo affects the processing machinery and carbohydrate contained in bamboo plays vital role in the durability of the bamboo [13].

b. Physical and Mechanical Properties: The physical and mechanical properties of bamboo vary with the age of the bamboo and the height of the Culm. According to [14], the increase in weight of the culm depends on age of the bamboo. The density of bamboo culm is as a result of the distribution of fiber around the vascular bundle of the culm. Though, the light weight of bamboo makes it to perform better in shear stress than materials of greater mass as noted by [14].

GENETIC DIVERSITY

Giant bamboo (*Dendrocalamus giganteous*) and green bamboo (*Bambusa vulgaris*) occur naturally in low to mid altitude areas with relatively high annual rainfall Punjab (India) has six bamboo species *viz*., *Bambusa balcooa*, *Bambusa bambos*, *Bambusa nutans*, *Bambusa tulda*, *Bambusa vulgaris* and *Dendrocalamus strictus*. Beema bamboo is a fast growing, dense, thornless and thick-walled sterile variety well suited as a power generation biomass feedstock. Beema bamboo (*Bambusa Balcooa*) is developed from the open pollinated population of bamboo found in West Bengal, A spacing of 5m x 5m may be sufficient for many bamboos but is inadequate for large species like *Dendrocalamus giganteus*, *Dendrocalamus brandisii*, or *Dendrocalamus asper*.which are normally planted at 10m x10m spacing [11]. Three primary native species in Nigeria - *Oxytenanthera abyssinica* and Bambusa vulgaris and ornamental bamboo Most of the Culms colour is green except garden bamboo that are black (*Phyllostachys nigra*). Widely cultivated species already used in significant quantities. These species are therefore prime candidates to be promoted as global priority species. In most cases, the information available on various parameters for these species is not adequate [11].

Priority species

1. *Bambusa balcooa*
2. *Bambusa bambos*
3. *Bambusa blumeana*
4. *Bambusa polymorpha*
5. *Bambusa textilis*
6. *Bambusa tulda*
7. *Bambusa vulgaris*
8. *Schizostachyum pergracile*
9. *Dendrocalamus asper*
10. *Dendrocalamus giganteus*
11. *Dendrocalamus latiflorus*
12. *Dendrocalamus strictus*
13. *Gigantochloa apus*
14. *Gigantochloa levis*
15. *Gigantochloa pseudoarundinacea*
16. *Guadua angustifolia*
17. *Melocanna baccifera*
18. *Ochlandra spp.*
19. *Phyllostachys pubescens*
20. *Thyrsostachys siamensis*

Fig 2: More versatile and useful species of Bamboo globally [11]

PROPAGATION AND MULTIPLICATION

Growing bamboo starts with obtaining the materials for planting. Such materials may come in the form of seeds, wildings, offsets or cuttings that may be gathered from the mother plant.

Propagation from seed

Once a bamboo stand or clump has flowered, seeds can be collected within the flowering period and seedlings raised as outlined below:

i. Because of poor viability of seed, it is more desirable to collect and sow the seed without delay.

ii. Sow seeds in the nursery bed. Cover with a thin layer of soil and water daily. Watering should be done carefully using a fine rose can.

iii. When germinated seedlings attain a height of 3 cm, they are carefully transplanted into growing medium.

iv. After 3-6 months, good-sized transplants are obtained. Seedlings over one year old establish better. Where roots of seedlings have not developed well, such seedlings may be maintained in the nursery for over one year.

Propagation using vegetative propagation means; vegetative parts such as culm cutting, branch cutting, rhizome division can be used to propagate bamboo. Therefore, each country needs to discover the proper method and the prevailing conditions of propagation for their own bam-boo species. Branch cutting was possible to propagate some bamboos as *Gigantochola verticillata* and *Sinocalamus oldhami* [2]. Use of culm cuttings has several advantages. Multiplication of many clumping species is possible by this method. When out-planted, vegetative materials raised from cuttings develop into clumps much faster than offsets and even seedlings. Offsets (rhizome with attached section of stem) are commonly used but their extraction is laborious and time consuming. However, using branch cuttings showed poor rooting percentages as pointed by [15].

a) **Culm Cutting**: Culm cutting involves dividing mature bamboo culms into sections, each containing one or more nodes, and planting them to propagate new bamboo plants. [6], emphasize that culm cutting is a viable method for bamboo propagation, where segments of established culms with healthy nodes can be carefully separated and planted to encourage the growth of new shoots.
b) **Branch Cutting:** Branch cutting refers to taking cuttings from the branches of bamboo plants and planting them to produce new shoots and ultimately form new plants. [6], highlights the significance of branch cutting as a propagation method for bamboo, particularly in species where branch cuttings can effectively grow roots and develop into individual plants.
c) **Rhizome Division:** Rhizome division involves separating and replanting the underground rhizomes, or root structures, of bamboo plants to establish new shoots and expand bamboo populations. [16], discuss the use of rhizome division as a method of bamboo propagation, noting that dividing bamboo rhizomes is an effective way to propagate certain bamboo species and create new bamboo plants for various purposes.

By utilizing these vegetative propagation methods, bamboo growers and enthusiasts can efficiently propagate bamboo plants and expand bamboo populations for conservation, landscaping, and commercial purposes.

Bamboo Tissue Culture and Micro Propagation

Bamboo tissue culture and micropropagation are advanced propagation techniques that involve growing bamboo plants from individual cells in a laboratory setting. These methods are valuable for reproducing bamboo plants on a large scale, preserving rare or endangered species, and producing disease-free plant material. Here is an overview of bamboo tissue culture and micropropagation below:

a) **Bamboo Tissue Culture**: Bamboo tissue culture involves growing bamboo plants from tissue explants (small sections of tissue) in a controlled environment using sterile conditions and nutrient media. [17], discuss the importance of tissue culture techniques in bamboo propagation, highlighting the ability to produce large numbers of uniform and disease-free bamboo plants through tissue culture methods.
b) **Micropropagation of Bamboo**: Micropropagation of bamboo refers to the propagation of bamboo plants through the multiplication of tiny plant parts, such as shoot tips or nodal segments, in a sterile culture medium containing nutrients and growth regulators. [18], discuss the significance of micropropagation techniques in the sustainable management of bamboo resources, emphasizing the ability to rapidly multiply bamboo plants and conserve genetic diversity through controlled environments.

Tissue culture and micropropagation offer several advantages for bamboo propagation, including rapid multiplication of plant material, production of disease-free plants, conservation of rare and endangered species, and the maintenance of genetic diversity within bamboo populations. By utilizing tissue culture and micropropagation techniques, researchers, nurseries, and conservation organizations can enhance the propagation and conservation of bamboo species, contributing to their preservation and sustainable utilization.

BAMBOO NURSERY AND PLANTATION ESTABLISHMENT

Fig:3. Bamboo stem cuttings in a screen house [11].

Establishing a bamboo nursery and plantation is essential for the successful cultivation and propagation of bamboo plants. A well-designed nursery and plantation layout, along with proper There are certain factors to consider before establishing a bamboo nursery or plantation which are briefly discussed below:

a. Bamboo Nursery Establishment:

- Site Selection: Choosing a suitable location for the bamboo nursery is critical. The site should have access to adequate sunlight, water sources, and proper drainage to ensure optimal growth conditions for the bamboo seedlings [19].
- Nursery Infrastructure: Constructing proper infrastructure such as shade structures, irrigation systems, seedling trays, and potting areas is essential for the efficient management of the bamboo nursery [20].
- Nursery Care: By Providing appropriate care for the bamboo seedlings, including watering, fertilization, pest control, and regular monitoring of plant health, is necessary for the successful establishment of the nursery [6].

b. Bamboo Plantation Establishment:

- Site Preparation: Before planting bamboo in the field, proper site preparation is essential. This may involve land clearing, soil testing, and soil amendment to ensure optimal growing conditions for the bamboo plants [21].
- Planting Techniques: Depending on the bamboo species and planting objectives, different planting techniques such as direct planting of culms, rhizome division, or transplanting seedlings can be used to establish the bamboo plantation.Gaint bamboo species like). *Dendrocalamus giganteus*, *Dendrocalamus brandisii*, or *Dendrocalamus asper* can be planted at 10m x10m spacing while medium growing species like *Bambusa vulgaris* can be planted at 5m x 5m spacing and small sized bamboo species like- *Oxytenanthera abyssinica* can be planted at 3m x 3m spacing [22].

Pest Management

- Identification of Pests: Regularly monitor bamboo plants for signs of pest infestations, such as leaf discoloration, holes in leaves, or wilting. Identify the specific pests affecting the bamboo plants to determine the appropriate control measures [23].
- Integrated Pest Management (IPM): Implement an integrated pest management approach that combines cultural, physical, and biological control methods with the judicious use of pesticides, if necessary. This approach helps minimize pesticide use and maintains ecological balance [24].
- Natural Predators: Encourage the presence of natural predators and beneficial insects in the bamboo plantation to help control pest populations naturally. Avoid indiscriminate pesticide applications that may harm beneficial insects [25].

Disease Management

- Preventive Measures: Maintain good sanitation practices, such as removing diseased plant material and debris, to prevent the spread of diseases in the bamboo nursery and plantation. Proper airflow and spacing between plants can also help reduce disease incidence [26].

By implementing proper irrigation practices and effective pest management strategies, bamboo growers can promote healthy plant growth and minimize the impact of pests and diseases on bamboo cultivation. By establishing a well-organized bamboo nursery and implementing proper plantation establishment practices, bamboo growers can ensure the healthy growth and sustainable management of bamboo plants for various purposes, including conservation, landscaping, and commercial cultivation.

BREEDING APPROACHES

Genetic improvement of economically important bamboo using conventional approaches is severely limited by the unique semelparous (monocarpic) flowering behaviour. This behaviour is characterised by long inter-mast periods and simultaneous gregarious flowering followed by death of the entire flowering cohort in most species [11]. The long flowering cycles and its unpredictable nature imposes a hurdle in planning any breeding programme. Except for a few species, bamboo has not been domesticated long enough for us to understand the genetic structure and the distribution of variability in wild populations. Bamboos are predominantly outcrossing species. Seeds therefore do not breed true. Use of seeds to generate planting stock will result in a genetically heterogenous population. Selection of superior individuals will be possible only after 3–5 years, when clumps have matured, [11]. The use of molecular methods is sure to hasten and improve our understanding of genetics and enable early selection, but for the present this practice is still under development. Meanwhile, bamboo genetic improvement will have to depend on an alternative trialing and clonal propagation strategy, Survey and assessment of genetic variability available in natural populations or in farmers' fields of the economically important bamboo species. ii. Collection of accessions within each species representing the intra-specific genetic variability and their conservation as part of in situ and ex situ germplasm collections. iii. Characterisation of the accessions at the morphological, physicochemical, and genetic levels based on parameters relevant to important applications. iv. Selection of superior accessions in economically important species that match current requirements for traditional and industrial applications and emerging ones. v. Field testing of selected accessions in multilocational field trials to assess performance and to enable site-species and site-clone matching [11]. vi. Mass clonal propagation of the selections to enable their use in multi-locational testing. vii. Make the high performing clones available for operational planting in commercial bamboo plantations. Much of the planting of bamboo in plantations is still done with bulk seed material obtained from gregarious flowering events and the seedlings derived from those seeds. While this helps maintain some genetic variability in bamboo plantations, it does little to improve productivity. There is an urgent need to identify and select quality mother clumps (known as candidate plus clumps, CPC) of useful bamboo species to serve as the source of vegetative material for clonal propagation. This material, including rhizomes, offsets, branches, culm segments, and buds, can be used to produce quality planting material. The clumps must be selected at an adult stage, usually 6–8 years old, so that the phenotype (morphological and physicochemical characteristics) is adequately expressed. The selected clumps should be of desirable form, free of diseases and pests, and high yielding with a high annual culm production rate or total biomass/hectare. Selection, when carried out from populations across the natural range of the species, provides for a larger number of CPCs for a wider genetic base in plantations of the future [11].

CONSERVATION APPROACHES

Historically, bamboo has mainly been extracted on a small scale from forests and homesteads with no attempt at scientific resource management or large-scale cultivation. Except for a few species, most bamboos have no history of domestication. Consequently, there has been little effort expended to develop optimal cultivation procedures, propagation methods or genetic improvement. Nevertheless, the importance of bamboo for rural economies has been widely recognised even as natural resources continued to be exploited. The INBAR-IBPGR Consultative Meeting on the Selection of Priority Species of Bamboo and Rattan in 1993 marked the beginning of efforts to select species based on the economic importance and potential for largescale cultivation [27]. Descriptions of the morphological characteristics of bamboo are found in taxonomic reports, which are insufficient for providing data on parameters of silvicultural importance. As emphasised by [23], conservation of bamboo genetic resources is of paramount importance. This is particularly so because many economically important species occur outside primary forests and are subject to threat of habitat loss and genetic erosion. There have been few comprehensive programmes to survey and study wild populations of bamboo species and to conserve the germplasm, whether in situ in nature reserves or ex situ in live collections. Unlike with important forestry species, no specific efforts aimed at conservation of bamboo genetic resources in their natural habitat have been initiated. Some work has been done to survey and collect germplasm for ex situ germplasm banks and bambuseta, and some exchange of species as planting material for plantations has been carried out between countries [11]

USES OF BAMBOO

Bamboo is a versatile and sustainable natural resource that has been utilized for a wide range of applications throughout history. With its strength, flexibility, and eco-friendly properties, bamboo has become a popular choice for various industries and products.

Traditional Uses of Bamboo: Timber, Crafts, Medicine and Food

Bamboo has been an integral part of human culture and civilization for centuries, serving a diverse array of traditional purposes across different regions of the world. From its use as a building material to crafting, medicinal remedies, and culinary delights, bamboo has played a vital role in various aspects of daily life. Here are some traditional uses of bamboo in timber, crafts, medicine, and food:

a. Bamboo as Timber: Traditional Building Material: Bamboo has long been used as a primary building material for constructing houses, bridges, fences, and other structures. Its strength, flexibility, and availability have made it a preferred choice for traditional construction in many cultures [28].

b. Tools and Implements: Bamboo has been utilized to craft a wide range of tools and implements, including fishing rods, bows and arrows, agricultural tools, musical instruments, and household items like baskets and containers [18].

c . Bamboo Crafts: Traditional Artifacts: Bamboo is intricately woven and shaped into a variety of crafts and artifacts, such as baskets, hats, mats, furniture, musical instruments, and decorative items. Skilled artisans use bamboo to create unique and culturally significant products [29].

Fig 4: A picture of bamboo as Craft [30].

Bamboo in Medicine

Traditional Remedies: Various parts of the bamboo plant, including the shoots, leaves, and sap, have been used in traditional medicine systems for their therapeutic properties. Bamboo has been used to treat ailments such as fevers, respiratory conditions, indigestion, and skin disorders [25].

Bamboo in Food

Culinary Delights: Bamboo shoots are a popular ingredient in traditional cuisines across Asia and other regions. The tender shoots are cooked and eaten in a variety of dishes, adding a unique flavor and texture to soups, stir-fries, curries, and salads [23]. Bamboo shoots are young culms harvested after it appears above the soil surface. Bamboo shoots have immense potential of being used as important health food as they contain high proteins, amino acids, carbohydrates, many important minerals, and vitamins. Freshly collected bamboo shoots have good amount of thiamine, niacin, vitamin A, vitamin B6, and vitamin E [31]. Tender shoots of *Dendrocalamus giganteus*, *D. hamiltonii*, *D. membranaceus* and *D. strictus* are consumed as vegetables and prickles either raw or cooked. The traditional uses of bamboo in timber, crafts, medicine, and food reflect its cultural significance and versatility as a natural resource.

Modern Uses of Bamboo: Paper, Textiles, Charcoal, Bioenergy

In addition to its traditional applications, bamboo has gained increasing popularity in modern times for its sustainable and versatile properties. From producing paper and textiles to generating charcoal and bioenergy,

bamboo offers a range of eco-friendly solutions for various industries. Here are some of the modern uses of bamboo in paper production, textiles, charcoal manufacturing, and bioenergy generation such as:

a.Bamboo in Paper Production:

Sustainable Pulp Source: Bamboo fibers are used to manufacture paper and paper products due to their strength, resilience, and high cellulose content. Bamboo pulp is recognized for its environmentally friendly attributes as a renewable resource for the paper industry [32].

b.Recyclable Packaging: Bamboo-based paper is increasingly used for packaging materials, including cartons, boxes, bags, and tissue paper. The recyclability and biodegradability of bamboo paper make it a sustainable alternative to conventional paper products [25].

c.Bamboo in Textiles: Bamboo fibers are used in the textile industry to create soft, breathable, and moisture-wicking fabrics for clothing, towels, bed linens, and other textiles. Bamboo textiles are favored for their comfort, durability, and eco-friendly properties [29].

d.Bamboo Charcoal: Bamboo charcoal is produced by carbonizing bamboo at high temperatures and is used for air and water filtration, as well as odor absorption. Bamboo charcoal's porous structure and natural purification properties make it an effective eco-friendly filter medium [28].

Fig 5: A picture of bamboo charcoal [28].

Bioenergy Generation from Bamboo

Renewable Energy: Bamboo biomass is utilized as a sustainable source of bioenergy for generating heat, electricity, and biofuels. Bamboo pellets and charcoal are used as clean energy alternatives in cooking, heating, and power generation. Beema bamboo (*Bambusa Balcooa*) is a fast growing, dense, thornless and thick-walled sterile variety well suited as a power generation biomass feedstock. [18]. The modern uses of bamboo in paper production, textiles, charcoal manufacturing, and bioenergy generation demonstrate the diverse applications of this versatile and sustainable material in contemporary industries.

Uses of Bamboo as an Agent of Soil Conservation and Erosion Control

Bamboo plays a crucial role in soil conservation and erosion control due to its extensive root system, rapid growth, and ability to stabilize sloping land. As a versatile plant with strong roots that hold soil together, bamboo is highly effective in preventing soil erosion, promoting water infiltration, and restoring degraded landscapes. Here are some key uses of bamboo in soil conservation and erosion control.

a. **Soil Stabilization**: The dense root network of bamboo plants helps to bind soil particles together, preventing soil erosion caused by water runoff, wind, and land degradation processes. Bamboo's fibrous roots contribute to soil stabilization and reduce the risk of landslides and soil loss in vulnerable areas [18].
b. **Slope Protection**: Bamboo is commonly used in watershed management and slope stabilization projects to protect hillsides and embankments from erosion. Its rapid growth and strong root system enable bamboo to establish quickly and provide natural barriers against soil movement and erosion [28].

c. **Riparian Restoration**: Bamboo is an effective plant species for restoring and conserving riparian zones along rivers, streams, and water bodies. Its deep root penetration helps to stabilize riverbanks, reduce sedimentation, and enhance water quality by preventing soil erosion and filtering pollutants [25].

d. **Contour Hedgerows**: In agroforestry systems, bamboo is often planted in contour hedgerows to create barriers that slow down water flow, trap sediment, and promote soil conservation on sloping agricultural land. Bamboo hedgerows help to reduce soil erosion, enhance water retention, and improve agricultural productivity [32].

The use of bamboo as an agent of soil conservation and erosion control demonstrates its ecological value and practical benefits in addressing environmental challenges.

Uses of Bamboo in Landscaping and as an Ornamental Plant

Bamboo is a versatile and aesthetically pleasing plant that is widely used in landscaping for its ornamental value, visual appeal, and functional properties. Whether used as a privacy screen, border plant, focal point, or ground cover, bamboo adds a unique touch to outdoor environments and brings a sense of tranquility and elegance to gardens, parks, and other landscaping settings. Here are some key uses of bamboo in landscaping and as an ornamental plant:

a. **Privacy Screening**: Bamboo provides an excellent natural solution for creating privacy screens and windbreaks in residential and commercial landscapes. The tall and dense growth habit of certain bamboo species makes them ideal for blocking views, reducing noise, and enhancing the privacy of outdoor spaces [5].

b. **Landscape Design**: Bamboo is a versatile plant that can be used in various landscape design styles, from contemporary and minimalist to tropical and Asian-inspired gardens. Its graceful culms, lush foliage, and architectural form make bamboo a popular choice for adding visual interest, texture, and structure to landscape compositions [29].

c. **Ornamental Value**:Certain bamboo species are prized for their ornamental qualities, including colorful culms, variegated foliage, and unique growth habits. Ornamental bamboo varieties are often grown in pots, planters, and garden beds to create focal points, borders, or accent features that add beauty and charm to outdoor spaces [29].

d. **Erosion Control**: Bamboo is utilized in landscaping to prevent soil erosion on slopes, embankments, and riverbanks. Its extensive root system helps to anchor soil, reduce surface runoff, and stabilize terrain, making bamboo an effective erosion control measure in landscapes prone to soil movement and degradation [18]. Bamboo's versatility, aesthetic appeal, and functional properties make it a valuable asset in landscaping and as an ornamental plant.

Air purification and carbon sequestration

Bamboo sequesters carbon better than terrestrial forests. It can sequester up to 17 tonnes per hectare per year of atmospheric carbon dioxide within the roots systems [2]. Bamboo provides tremendous restorative powers to degraded lands, clean soil and water of contaminants, mitigate erosion especially along water shades, restore moisture content and revitalize soil nutrients [2].

Wildlife support. Other animals besides lemurs and panda are dependent on bamboo. There is a community of rainforest organisms that rely on so-called bamboo wells, cavities in fallen bamboo culms that fill with rainwater. At least 4-5 per cent of all the bird species that occur in Amazonia are dependent on bamboo [33]. During dry season, many browsers and monkeys feed extensively on tender and unfurled leaves of bamboo [33].

CONCLUSION

The diverse range of bamboo species and their widespread distribution make them a valuable resource for various industries, including construction, textiles, and food production. In addition to their economic importance, bamboo species also play a crucial role in environmental conservation, as they help prevent soil erosion, promote water conservation, and contribute to carbon sequestration [16]. Bamboo is a versatile plant that can be used for a wide range of products, including construction materials, furniture, handicrafts, and textiles. By promoting sustainable cultivation and utilization of bamboo, communities can benefit from the economic opportunities that bamboo offers while ensuring that the resource remains available for future generations. Furthermore, sustainable bamboo propagation contributes to environmental conservation efforts by promoting carbon sequestration, soil conservation, and watershed protection. Bamboo plants have a high capacity for sequestering carbon dioxide and releasing oxygen, making them valuable allies in the fight against climate change. Sustainable cultivation practices also help to prevent soil erosion and protect water sources, safeguarding the health of ecosystems and communities that rely on them [36].

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