2017

Bamboo

Conservation, Management and Utilisation in India

A Status Report

Indian Council of Forestry Research and Education
Dehradun

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ICFRE, October 2017

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Foreword

India has vast bamboo resources, which can offset the raw material requirement of forest-based small and large industries, both in organized and unorganized sectors. Bamboo is climate friendly and has enormous potential for solving many problems of social and environmental sectors. The traditional bamboo industry has created plenty low-cost employment and livelihood opportunities. However, even after having second largest bamboo resource in the world, the full potential of bamboo has not been realized.

Promotion of bamboo sector has many opportunities and perspectives for supporting livelihoods of rural people. Government of India has realized this in the past and two specific centrally-sponsored missions were launched for the growth of bamboo sector. The National Bamboo Mission (NBM), later renamed as National Agroforestry and Bamboo Mission (NABM) was set up under Department of Agriculture and Cooperation (DAC), Ministry of Agriculture and Farmers Welfare, Government of India in 2007 to promote holistic growth of bamboo sector by adopting area-based, regionally-differentiated strategy and to increase the area under bamboo in potential areas with improved varieties for enhancing yield.

Subsequently, a National Mission for Bamboo Application (NMBA) was setup under Department of Science and Technology and was structured as a Technology Mission. NMBA was to create the basis for enlarging the bamboo sector by augmenting economic opportunity, income and employment through multi-disciplinary approach focused on value addition and commercialization; develop, test and disseminates technologies; support for entrepreneurial projects. The major thrust by NMBA was given to wood substitutes and composites, machinery and processing technologies, propagation and cultivation, bamboo for energy, industrial products and product applications.

ICFRE, under the World Bank supported Forest Research, Extension and Education Project (1994-2002), initiated a bamboo selection programme in respect of selected species from their natural populations and established rhizome banks with the selected germplasm across the country. In 2014, ICFRE took another step towards second stage selection of promising clumps from the established rhizome banks with financial support from the erstwhile National Bamboo Mission for species like *Bambusa vulgaris, B. tulda, B. nutans, B. balcooa, B. bambos, Dendrocalamus brandisii, D. hamiltonii, D. strictus, D. somdevai,* and *D. stocksii.* In addition to this, work has also been carried out through self-funded projects of ICFRE. IWST and IPIRTI at Bengaluru and FRI, Dehradun also developed technologies for utilization of bamboo as timber and composite material.

Besides efforts of ICFRE Institutes, some organizations and universities are also carrying out research on bamboo. However, bamboo sector is yet to attain its full potential. This report is an endeavour on the part of ICFRE to identify the issues related to extension of forest and non-forest areas under bamboo cultivation, improvement in productivity, availability of raw material to artisans and bamboo-based industries, improved utilization, market linkages and policy changes.

Scientists and officers of ICFRE have put their whole-hearted efforts in collecting and synthesizing the information from various sectors and organizations. I acknowledge the entire team for its effort and hope that this report will help the Government formalize suitable strategies for growth of bamboo sector in India.

- Dr. S.C. Gairola

Preface

Systematic forest research in modern times, started in India with the creation of Indian Forest Department in 1864 and took firm roots with the establishment of a dedicated Imperial Forest Research Institute at Dehradun in 1906. With the expansion of forestry research, Indian Council of Forestry Research and Education (ICFRE) was set up in 1988 as an autonomous organization in 1990. Since its inception, ICFRE has been effectively planning, steering and monitoring forestry research in the country through its nine institutes and has been continuously adjusting its research programmes to the national needs.

Bamboo is an important sector where ICFRE has been working on different aspects for past several years either through its own funds or through the projects supported by different funding agencies. During 2007-08, Bamboo Technical Support Groups (BTSG) was also established at ICFRE through financial assistance from the erstwhile National Bamboo Mission (NBM). BTSG-ICFRE with fund support from NBM/NABM has been continuously carrying out development activities through its nine Institutes. The main focus of BTSG-ICFRE has been on training, research and development for producing quality planting material, propagation protocols, wood substitutes from bamboo, creation of common facility centre (CFCs), developing audio-visual programmes, exposure visits to artisans, and conducting theme-based seminar/workshops on bamboo.

It is an apt decision to entrust the work of preparing 'Status Report on Bamboo' to ICFRE. The experience of past research work has helped considerably in preparation of this report. Organizations outside ICFRE, including research bodies, industries and growers were also consulted to provide the information which has been duly incorporated in various chapters of the report. Basic work of the compilation and synthesis of the information was done by teams of scientists and officers of domain areas at ICFRE Institutes. The information was then synthesized, edited and augmented into chapters by the Drafting Team at ICFRE Headquarters. Executive Committee members provided their inputs in the draft version of the report, which was then incorporated by the Drafting Team. The invaluable logistic support of ICFRE during preparation of the report is duly acknowledged.

We take this opportunity to thank all the team members and others who have contributed in compiling the report. Contribution of Drafting Team, who worked tirelessly with Dr. S.P.S. Kushwaha, Anchor for preparation of the report, is commendable. Cooperation of the Directorate of Research team in coordinating all the activities is also acknowledged. We sincerely hope that this report will be very useful in framing and developing new strategies for the growth of the bamboo sector in the country.

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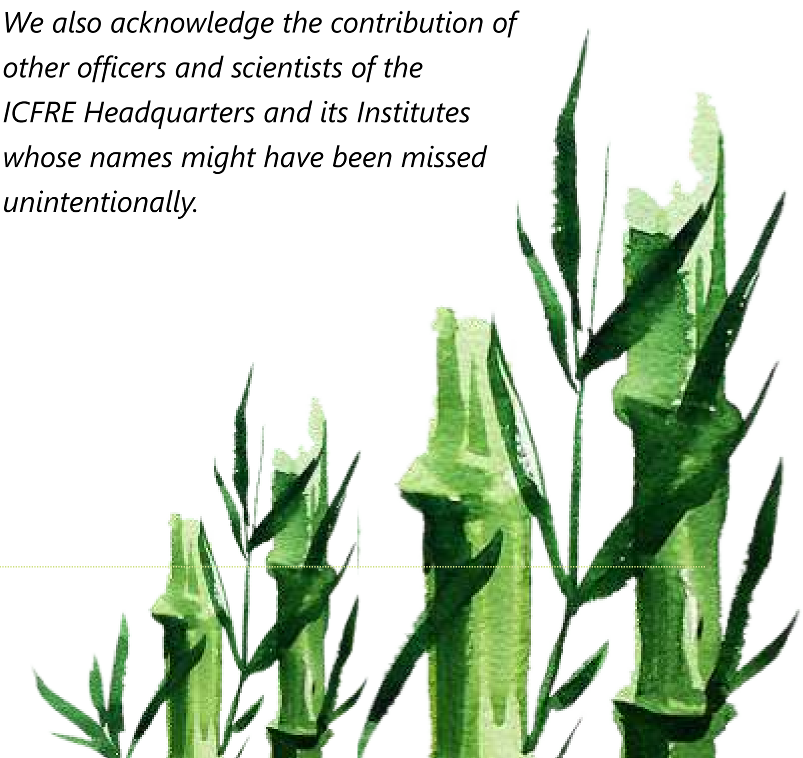

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

Bamboos are found naturally growing in 21 countries of the world between 46° N and 47° S latitudes and from sea level to 4000 metre altitudes. About 1 billion people in the world either live in bamboo houses or use it in their daily course of life. Over 6.3 million km^2 of Asian forests contain bamboo, with highest densities reported from the north-east India followed by Myanmar, south China, Sumatra and Borneo. Nearly 30 per cent of the total bamboo area in Asia is planted.

Bamboo is the tallest and fastest growing woody, perennial grass on earth with approx. 90 genera and 1200 species globally. India has highest area (13.96 million ha) under bamboo while China has highest bamboo diversity (144 species). India is the second richest bamboo diversity country with 136 species (125 indigenous and 11 exotic).

Plant height varies from a few centimetres to about 30 metres and the culm diameter can reach up to 30 centimeters. Sympodial bamboos form a compact clump, while monopodial bamboos grow into an open clump with dispersed culms. Most bamboos flower only once in their life time and all the clumps die after flowering.

Commercially, the most important species are *Bambusa balcooa, B. bambos, B. nutans, B. pallida, B. polymorpha, B. tulda, Dendocalamus brandisii, D. giganteus, D. hamiltonii, D. strictus, Melocanna baccifera, Ochlandra travancorica, Schizostachyum dullooa* and *Thrysostachys oliveri*. Their strength, straightness and lightness combined with extraordinary hardness, range of culm sizes, abundance, easy propagation and the short period in which they attain maturity make them suitable for a variety of purposes.

The annual production of bamboo in India is about 14.6 million tonnes and annual yield varies from 1 to 3 tonnes per ha. Pulp and paper industries use 35 per cent of the bamboo followed by housing and rural sectors. The bamboo and rattan industry of India is worth US$ 4.35 billion. India is a net importer of bamboo and the value of bamboo and rattan imports is US$ 24.19 million in contrast to exports worth US$ 1,237.60 million from China.

The bamboo industry in India is under-developed and uncompetitive. Low-value, poor-quality traditional articles are produced for domestic market through obsolete tools and techniques by unorganized individuals and small entrepreneurs with large wastages and high cost. The industry is in need of comprehensive reform.

Modern technologies allow use of bamboo as a durable and high-quality wood substitute. Premium products such as bamboo flooring, laminated furniture, mat boards, strand lumber, etc. have huge international demand with big pro-poor financial impact and employment potential. Bamboo bridges and pre-fabricated houses have large potential in defence, disaster management and low-cost housing. Pack-flat and knock-down furniture are novel concepts.

Several methods are available for propagation of bamboo from seed as well as through vegetative means, including tissue culture. Techniques for planting bamboo within and outside forest, including farmland, are known. Research is underway for development of superior planting material.

Bamboos are generally harvested under the culm selection system wherein mature culms are cut on a short felling cycle of three to five years. The ideal clump structure for commercial plantations has been worked out. Culms, if not harvested over a long time, begin to deteriorate and decay thereby reducing there economic value. Likewise, unmanaged clumps have low productivity and result in poor quality of produce due to congestion.

Silvicultural interventions like tending, decongestion, extraction and removal of defective culms, selective extraction, etc. are applied to preserve vigour and productivity of clumps. Clear-felling is used for monopodial bamboos extraction. The horse-shoe and tunnel systems are used for harvesting in sympodial bamboo clumps. Elaborate cutting rules are given in many working plans in India to streamline bamboo management and harvesting.

Bamboo is increasingly being planted by farmers on farm land. Bamboo-based agroforestry systems include homesteads, block plantations, wide-row intercropping, wind breaks and miscellaneous systems. However, relatively less information is available on intercropping options in agroforestry such as compatibility with crops, effect on crop yield and quality, optimum planting density and other management options.

Bamboo is affected by several insects and fungi during growth, storage and after product manufacture. Preventive and remedial measures employing physical, chemical and biological techniques are available. Integrated pest management is suggested for managing these problems.

Raw bamboo falls in class-III (non-durable category) and possesses little variation in durability among different species. However, with technology developed so far, its durability can be increased beyond 50 years if treated with preservatives. Pre-harvest and post-harvest treatments are effective in reducing damage by fungi and insects. Several preservatives have been developed and commercialised. It is also possible to treat bamboo with fire retardant chemicals but the cost is generally high. Finding a suitable and cost-effective treatment for protection against biodegradation and fire needs further research. The processes leading to engineered bamboo products also protect it against biodegradation.

The primary processing (harvesting, storage, transportation, preservation and seasoning) and secondary processing (fabrication of value-added products) technologies for bamboo are well-developed but there are problems in the bamboo transformation chain, *viz*., poor quality and low volume bamboo supplies, lack of trained labour, inadequate inputs in production, fragmentation of industry, multi-tasking by industry, long distance of industry from markets, absence of standardisation, under-developed markets and unfavourable perceptions of consumers.

ISO 2004 and National Building Code 2016 have prescribed standards towards use of bamboo in construction. Bamboo has been developed as a specially valuable and superior alternative to wood composites (plywood, fibreboard, etc.). Various types of bamboo veneers, panels and boards have been prepared; these can be classed as veneer-based boards, strip boards, mat boards, medium density boards, fibreboards, particle boards, bamboo lumber combinations of these and combinations of these with wood and other ligno-cellulose materials and inorganic substances.

Bamboo flooring is a quality product and has advantages over wooden floors due to its smoothness, brightness, stability, high resistance, insulation qualities and flexibility. Bamboo flooring has natural lustre and maintains the natural gloss and elegance of bamboo fibre. This flooring is attractive to the demanding markets in Europe, Japan and North America though share of India in the export so far is very small.

Bamboo handicraft sector is predominantly in the hands of small and cottage units and there are millions of people who depend on bamboo for part or all of their income. The potential of bamboo handicrafts has not been properly tapped in domestic and overseas market. The traditional market is declining largely due to irregular and inadequate supply of raw materials and lack of adequate marketing facilities. Traditional bamboo furniture uses natural round or split bamboo. A new type of 'pack-flat' 'knock-down' furniture uses glue-laminated bamboo panels. Unlike the traditional design, this furniture may be shipped in compact flat packs, to be assembled on the spot.

Bamboo has been a traditional raw material for making paper. Due to declining supplies of bamboo coupled with the availability of fast grown tree alternatives, the industry has begun to mix hardwood pulp with bamboo pulp for production of paper. Bamboo accounts for low fibre and pulp yield per hectare per year compared to softwood, hardwood, bagasse and elephant grass.

Bamboo has good potential in textiles. Bamboo fabric is breathable, remains odourless and does not cling to skin. Economical, ecological, aesthetically pleasing, comfortable and long-lasting fabric can be made of bamboo.

Bamboo shoots are low in calories, high in dietary fibre and rich in nutrients. Over two million tonnes of juvenile bamboo shoots are consumed in the world annually. Bamboo shoots also possess medicinal properties. Harvesting time is very critical for this use. Bamboo, as fastest growing terrestrial plant species on the earth, can also help to solve energy problems through briquetting and gasification. It is also used to make charcoal as fuel and as activated charcoal adsorbent for the water purification and in gas filters. It has high potential for bioethenol production.

The demand for bamboo in India outstrips the supply. Unfortunately, there has not been any substantial increase in the bamboo production in forests and on private lands over time. Also, there is an overall dearth of improved, disease and pest resistant planting material which may significantly boost bamboo production.

The production system in India is largely government- or community-owned and private plantations are negligible in area. Most of them are of small size as homestead plantations, mostly for self-use. Restrictions in felling apply only in respect of bamboo found in the forests, whereas public is required to obtain permits for harvest. Treatment of bamboo as a 'minor forest produce' (The Schedule Tribes and Other Traditional Forest Dwellers: Recognition of Forest Rights Act, 2006) and removing restrictions on its harvest through an amendment in the Indian Forest Act, 1927 is imperative.

A comparison with China shows that bamboo removal in India is only 1 per cent of China despite having 208 per cent greater bamboo area *vis-à-vis* China and almost an equal population to support. The growing stock in India is 74.3 per cent of China. An analysis of the bamboo sector of China and other countries suggests that raw material stock and research backup in India are sufficient to speedily move towards development of a strong bamboo industry in India. The need for specialised tools and machinery, which may be manufactured by domestic companies in due course of time, can be initially met through imports.

Lack of capital investment by industry, sub-optimal harvests, restrictive harvest rules, fragmented value chain and disconnect from international market are the five biggest factors identified in this report that restrict the growth of the bamboo sector. Uncoordinated steps by multiple regulatory ministries are not allowing improvement of the sector.

The recommendations evolved for improvement of the bamboo sector have been summarised as follows :

1. Investment should be mobilised on a massive scale through private sector participation in setting up bamboo value chain using a cluster approach. Industrial units in the cluster should be encouraged to attain species- and product-specific specialisations for producing end-products of high quality and modern design suiting domestic and international demand.
2. Pilot projects should be launched in different regions of India integrating bamboo producers, primary and secondary processing units, skill development centres, research and technology institutions, markets and all other players in the value chain.
3. For an expanding industry, progressively increasing supplies of bamboo should be ensured by SFDs – custodians of world's largest bamboo resources – by working bamboo on silvicultural rotation, liberalising its harvest and transit, and managing bamboo extraction and sale with active involvement of local institutions. Separate rules should be framed for regulating extraction of bamboo from protected areas.
4. Degraded bamboo bearing areas should be rehabilitated through silvicultural interventions to meet

the twin objectives of regenerating bamboo and augmenting raw material supply. The approach of 'Integrated Land and Ecosystem Management to Combat Land Degradation and Deforestation' project implemented by Madhya Pradesh Forest Department with the help of local communities may be followed.

5. Planting of bamboo on private, community, wasteland and other potential areas should be promoted through lease of land to industry, contract farming, farmer-industry buy-back agreement mechanism, credit facilities, minimum support price, extension support and bamboo nursery network.
6. Use of bamboo must be promoted through publicity, branding, exposure of architects/builders and ensuring greater use of bamboo in government housing schemes, civil and defence construction and furnishing.
7. The bamboo sector should be treated as a priority sector and the bamboo and bamboo-products should be accorded tax concessions and incentives as has been done in the case of raw material and finished products of khadi industry.
8. Linkage should be promoted among raw material suppliers, artisans, pre-processing industries, manufacturers, sellers and exporters through traditional and digital modes of communication.
9. Bamboo cooperatives must be formed to help people collectively take up bamboo production, management, raw material procurement, processing, value addition, manufacturing, marketing and sale.
10. Business development help desk should be created at district or block level for providing information to producers, for business counselling, market information, technology information and preparation of business plan.
11. A strong mechanism must be developed for database development, including management information system (MIS), and continuous updating of the information.
12. The existing research institutions should be strengthened for focused research, technology development and extension support to the bamboo sector.
13. Technology and training institutions should be entrusted with the task of development of state-of-the art machines, tools and skilled manpower to support an efficient bamboo industry.
14. Handicrafts, bamboo shoots, premium processing industries (e.g. flooring, laminated furniture, panel), medium-value processing industries (e.g. matboard, blinds, chopsticks) and low-value bulk processing industries (e.g. paper and pulp, alcohol) have decreasing pro-poor financial impacts per ha and should be accorded priority in descending order, other things being equal.
15. National Bamboo Development Board should be established on the lines of Tea Board, Coffee Board, etc. for promotion of bamboo sector and addressing its problems in a holistic way.
16. A specialised agency should be designated to develop and enforce quality standards for bamboo products.
17. A National Bamboo Policy should be framed and implemented for development of the bamboo sector.

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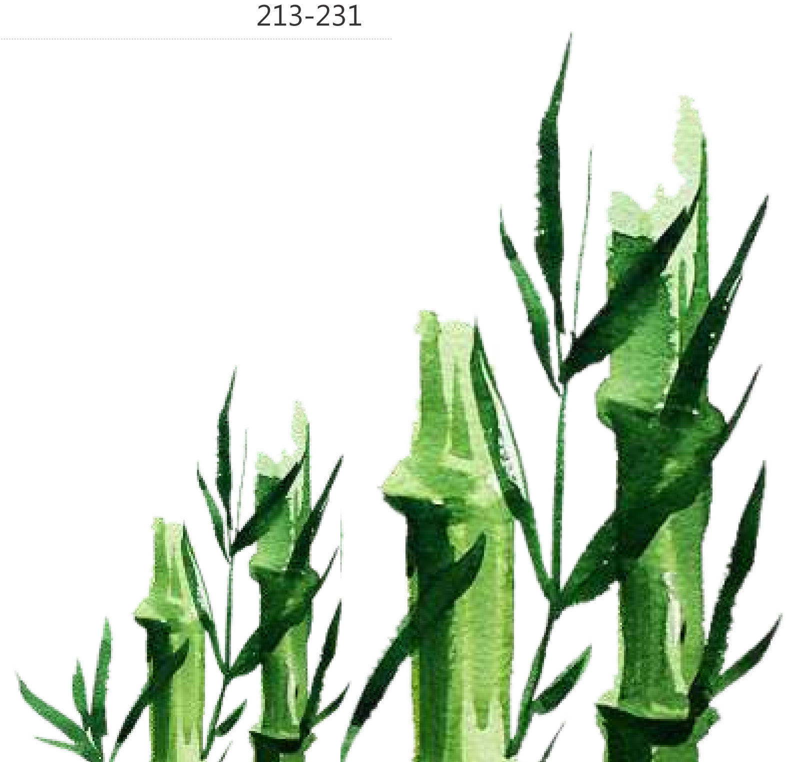


SECTION-I

Overview of Bamboo Scenario in the Country

CHAPTER - 1

INTRODUCTION

1.1 The Plant

Bamboo, the tallest and the fastest growing (up to one metre per day) woody perennial grass on planet earth, belongs to family Poaceae with about 1,200 species reported globally (Lobovikov *et al.*, 2007). Height of bamboo species varies from a few centimetres to about 30 metres and can reach to a diameter of up to 30 centimetres. Because of wide adaptability and utility bamboos are ecologically, socially, commercially and environmentally important group of plants. They flowers rarely and in irregular cycles, which are not yet clearly understood. Taxonomists thus face great difficulty in identification of bamboos. The identification of bamboos is mostly limited to culm sheath characters. DNA-based molecular biology approaches shed new light on bamboo taxonomy and the work is in progress to develop DNA barcodes for authentic identification of the species. Bamboo shoots (or culms) are generally hard and the plant can survive and regenerate after severe calamities, catastrophes and damage.

Underground stem (called rhizome) is fleshy from which shoots and roots emerge. There are two main categories of rhizomes: monopodial and sympodial. Monopodial rhizomes grow horizontally, often at a surprising fast rate, and thus nicknamed as 'runners'. The rhizome buds develop either upward, generating a culm, or horizontally, creating a new tract of the rhizomal net. They generate an open clump with culms distant from each other and can be invasive. Monopodial bamboos are usually found in temperate regions and include genera, *Phyllostachys* and *Pleioblastus*. Sympodial rhizomes are short and thick, and the culms above ground are together in a compact clump, which expands evenly around its circumference gradually. Most bamboo flower and fruit once in their lifetime and hence, referred to as monocarpic. Entire clump dies after flowering and seeding (Janzen, 1976).

1.2 Distribution

Bamboo occurs in the latitudinal range from 46° N to 47° S and altitudinal range of 0-4000 m from mean sea level covering tropical, subtropical, temperate and alpine regions (Dransfield, 1992) of Africa, Asia and Central and South America (Fig. 1.1). Bamboo has been introduced into north America, Europe and Australia (Pannipa Chaowana, 2013). Five out of six countries, viz., India, China, Indonesia, Myanmar, and Vietnam have large extent of bamboo forests in Asia. Latin America has 10 million ha of the total over 36 million ha bamboo area in the world whereas Africa has the smallest bamboo area of 2.7 million ha (FAO, 2005). Bamboos generally prefer well-drained sandy loams to loamy clay soils and thrive well at annual temperatures range of 8.8-36° C and rainfall of 1,270-4,050 mm. Bamboo is an extremely diverse plant, which easily adapts to different climatic and soil conditions (Lobovikov *et al.*, 2007). Over 24 million ha of Asian forest potentially contains bamboo, with highest densities indicated from north-eastern India through Myanmar to southern China, and through Sumatra to Borneo. The highest species richness (144 species per km^2) in reported from the forests of south China (Bystriakova *et al.*, 2003). Nearly 30 per cent of the total area of bamboo in Asia is planted (ftp://ftp.fao.org/docrep/fao/010/a1243e/a1243e03.pdf.).

In India, bamboo occurs in different bio-climatically-defined vegetation types ranging from tropical to subalpine zones, more so in disturbed habitats. The diversity has considerably dwindled in natural habitats due to over-exploitation, shifting cultivation, gregarious flowering and extensive forest fires. Indiscriminate removal of forest cover has resulted in the gregarious growth of certain species of bamboo only, which has reduced species diversity in the areas of their natural occurrence. Appreciable bamboo diversity can be observed in undisturbed national parks and wildlife sanctuaries in India. Fig. 1.2 depicts major bamboo species distribution in India (FSI, 2011).

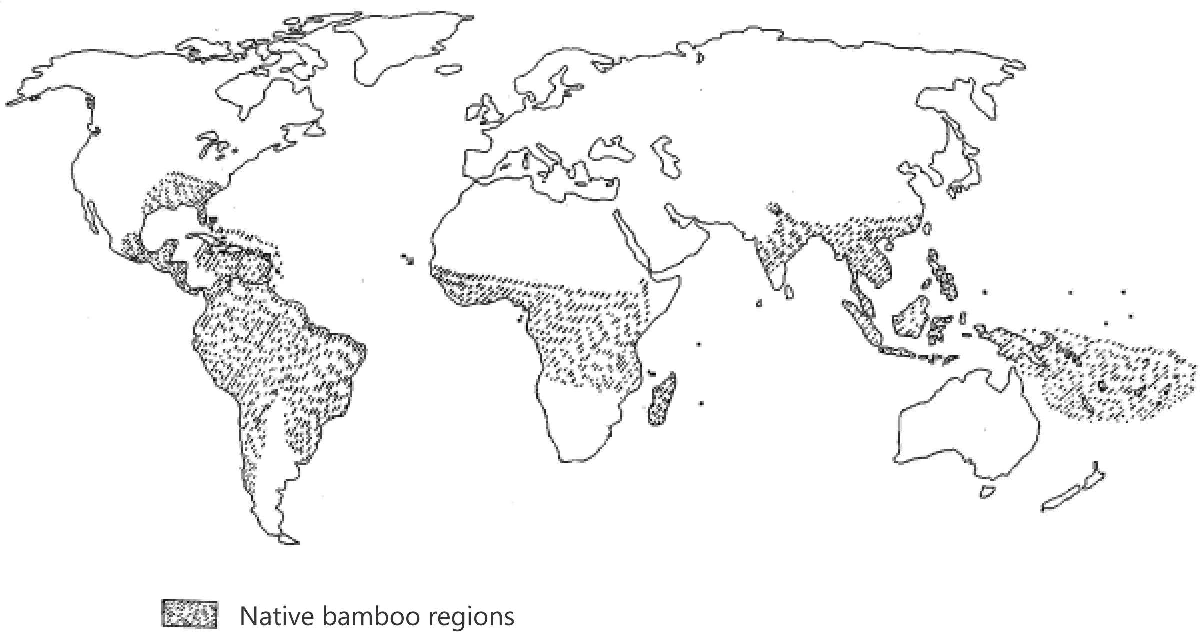


Fig. 1.1: Global distribution of bamboo (Redrawn from El Bassam and Jakob, 1996)

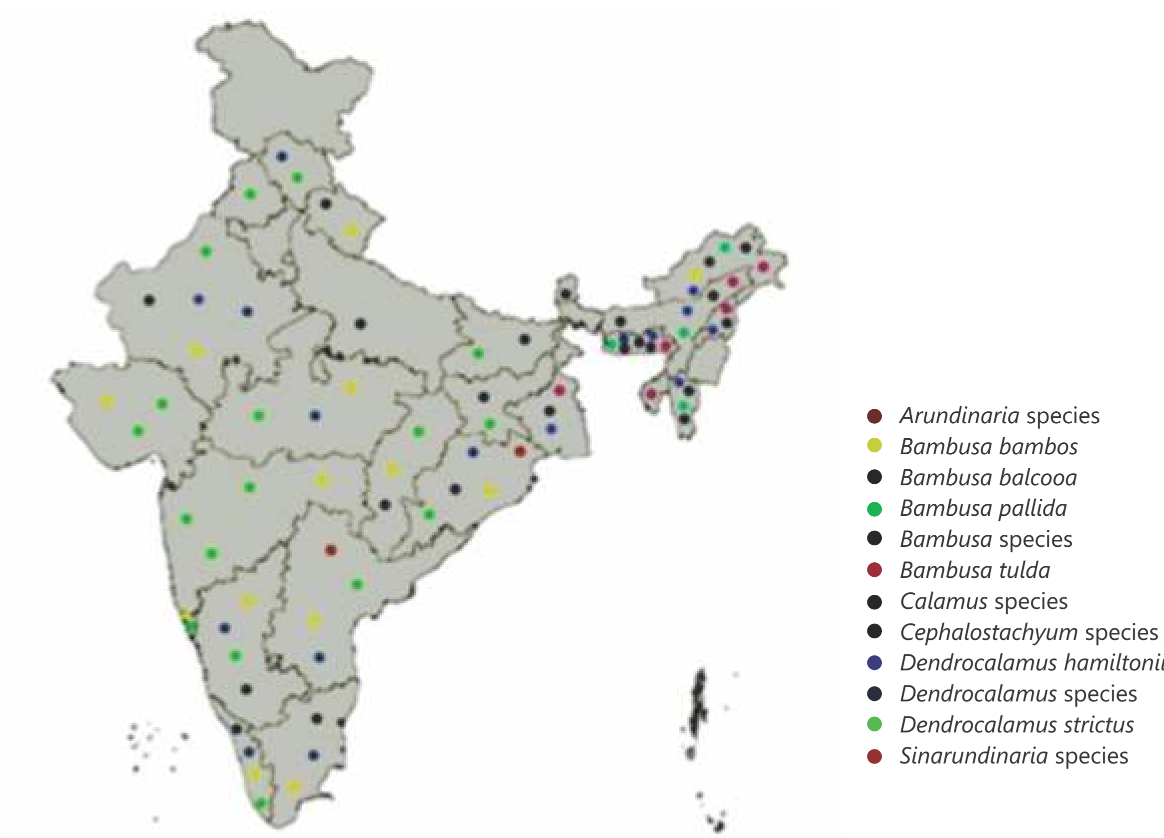


Fig. 1.2: Distribution of major bamboo species in India (Source: FSI, 2011)

India is the second richest country in bamboo genetic resources after China. These two countries together have more than half the total bamboo resources globally. Sharma (1987) reported 136 (125 indigenous and 11 exotic) species of bamboo occurring in India. Fifty-eight species of bamboo, belonging to 10 genera, are distributed in the north-eastern states alone. More than 50 per cent (71 species) of the bamboos found naturally occurring in India are endemic to the country (Sharma, 2015). Bamboo covers about 13.96 million ha area in India (FSI, 2011), which is 18.14 per cent of the recorded forest area in the country. Arunachal Pradesh has maximum area under bamboos (1.5 million ha), followed by Madhya Pradesh (1.3 million ha), Maharashtra (1.15 million ha) and Odisha (1.03 million ha). The largest occurrence of pure bamboo stands is in Mizoram (226 km^2), followed by Arunachal Pradesh (217 km^2), Manipur (192 km^2) and Nagaland (101 km^2). Dense bamboo forests are found in Arunachal Pradesh (8,681 km^2), followed by Mizoram (6,116 km^2) and Manipur (5,825 km^2). Table 1.1 shows State- and Union Territory-wise bamboo bearing area by density classes in recorded forest area (Tripathi *et al.*, 2015).

Table 1.1: State- and union territory-wise bamboo bearing area by density classes in recorded forest area (km^2) (Source: FSI, 2011)

State/UT	Pure bamboo	Dense	Scattered	Bamboo present but clumps completely hacked	Regene-ration crop	Total	Recorded forest area
Andhra Pradesh*	26	1,795	3,963	309	2,091	8,184	63,814
Arunachal Pradesh	217	8,681	6,953	144	88	16,083	51,540
Assam	105	4,049	2,878	166	40	7,238	26,832
Bihar	1	239	393	75	31	739	6,473
Chhattisgarh	54	3,046	4,577	1,496	2,195	11,368	59,772
Dadra & Nagar Haveli	0	15	28	3	9	55	204
Goa	0	40	212	12	44	308	1,224
Gujarat	0	799	2,408	367	517	4,091	18,927
Haryana	0	3	9	7	0	19	1,559
Himachal Pradesh	0	37	422	24	25	508	37,033
Jharkhand	14	898	1,571	509	611	3,603	23,605
Karnataka	0	1,925	4,390	297	1,574	8,186	38,284
Kerala	0	461	2,105	86	230	2,882	11,265
Madhya Pradesh	76	2,732	5,264	2,284	2,703	13,059	94,689
Maharashtra	56	2,618	4,604	1,468	2,719	11,465	61,939
Manipur	192	5,825	3,101	124	61	9,303	17,418
Meghalaya	63	2,815	1,830	68	17	4,793	9,496
Mizoram	226	6,116	2,757	104	42	9,245	16,717
Nagaland	101	3,064	1,644	65	28	4,902	9,222
Odisha	35	2,479	5,230	1,066	1,708	10,518	58,136
Punjab	0	5	39	31	0	75	3,058
Rajasthan	0	516	1,188	333	418	2,455	32,639
Sikkim	0	481	684	8	8	1,181	5,841
Tamil Nadu	5	650	1,707	130	773	3,265	22,877
Tripura	67	2,039	1,079	43	18	3,246	6,294
Uttar Pradesh	2	311	647	189	164	1,313	16,583
Uttarakhand	0	67	329	47	8	451	34,651
West Bengal	0	362	582	58	40	1,042	11,879
Total	**1,240**	**52,068**	**60,594**	**9,513**	**16,162**	**139,577**	**741,971**

*including Telangana

Bambusa vulgaris cv. *wamin*

Bambusa vulgaris cv. *striata*

Dendrocalamus longispathus

Dendrocalamus giganteus

Bambusa multiplex

Bambusa ploymorpha

Dendrocalamus somdevai

Dendrocalamus hamiltonii

Bambusa balcooa

Important Species of Bamboo with Common Names

Scientific name	Vernacular names	English name
Bambusa bambos (syn. *B. arundinacea)*	Baans, Magar baans, Mula, Jaati baansh, Bidiru, Baansha, Kanta Baans	Indian thorny bamboo, giant thorny bamboo
Bambusa vulgaris	Baans, Wa, Mula, Moongil	-
Bambusa nutans	Bidhali, Mukial, Seingjai, Pihli	-
Bambusa pallida	Kalinga, Bijli, Makal, Loto, Ka-Sken, Shen	-
Bambusa ploymorpha	Bethua, Bari, Paura, Narangi bans	-
Bambusa tulda	Baans, Tulda, Pheka, Torolabanso	-
Bambusa balcooa	-	-
Dendrocalamus asper	-	-
Dendrocalamus brandisii	-	-
Dendrocalamus giganteus		Dragon bamboo
Dendrocalamus hamiltonii	Maggar, Tama, Choya Bans, Kokwa, Wanok, Pecha	-
Dendrocalamus hookeri	Rawlak	-
Dendrocalamus latiflorus		-
Dendrocalamus longispathus	Ooei, Goti, Rawnal, Roopal, Orah	-
Dendrocalamus sikkimensis	Bhalu Bans, Pugriang, Wedah	-
Dendrocalamus stocksii (syn. *Pseudoxytenanthera stocksii)*	Marihal bamboo	-
Dendrocalamus strictus	Nar Baans, Baans, Bidiru, Kal-munkil, Karikana, Velu	Male bamboo, solid bamboo
Guadua angustifolia	-	-
Himalayacalamus falconeri	Deoringal	-
Melocalamus compactiflorus	Lota, Lotabans, Bethus bans, Kalibans	-
Melocanna baccifera	Muli, Artem, Mao, Watrai	-
Ochlandra travancorica	Eeral, Nanal, Eetta, Vei	-
Oxytenanthera parviflora	-	-
Phyllostachys bambusoides	-	-
Schizostachym dullooa	Tokre Bans, Puksalu, Dullooa	-
Thamnocalamus spathiflorus	Thaam Ringal, Parikh	-
Thyrostachys oliveri	-	-
Thyrostachys jaunsarensis	Jamura ringal	-

1.3 As a Resource

Bamboo has been associated with the humans from cradle to coffin since time immemorial. It has received increasing attention over the last three decades for its economic and environmental values. In Africa, Asia and Latin America, it is closely associated with the indigenous cultures and knowledge and is widely used in several livelihood activities. In countries undergoing economic development, traditional bamboo culture faces threat. However, industrial development of bamboo is offering a new opportunity to younger generations to retain and continue developing cultural traditions related to the cultivation, harvesting and use of bamboo. The physical and environmental properties of bamboo make it an exceptional economic resource for a wide range of uses and for poverty alleviation. It grows quickly and can be harvested annually without depletion and deterioration of the soil. It has great potential to transform the rural and tribal economies and contribute to sustainable development of the country.

Bamboo can grow on marginal land, not suitable for agriculture or forestry, or as an agroforestry/farm forestry crop. It has a relatively light weight and compares well with wood in strength. Unlike wood, it can be easily harvested without specialized equipment. It splits easily for weaving and is thus, easy to handle for women. Bamboo is often cultivated outside the forest on farms, where it is more easily managed. Processing normally does not require highly skilled labour or special qualifications and can be done by rural communities at a minimal cost. For the same reason, bamboo use and trade have been growing in recent years but not at the desired rate. Bamboo is becoming popular as an excellent substitute for wood in producing pulp, paper, board and charcoal. It is widely used in construction, either in its natural form or as a reconstituted material (laminated boards and panels). In addition, tender bamboo shoots have become a popular food material with Asian cuisine around the globe (Lobovikov *et al*., 2007).

It is also reported that about 2.5 billion people worldwide use bamboo and about 1.0 billion live in bamboo houses in the world. Bamboo industries in China alone generate more than US$ 2 billion (FAO, 2005). The bamboo is being considered as a major export item and valued at about Rs. 50 billion in the global market and the turnover of the bamboo sector in India is estimated to be around 2.5 billion. Since 1990s, the area under bamboo in China has been rapidly increasing at a rate of about 50,000 ha per year and has reached to about 5 million ha, which is a 1.5-fold increase compared to the 1950s. (Moso *Phyllostachys heterocycla* var. *pubescens)* represents 70 per cent of the bamboo in China. The average stock of moso bamboo has increased from less than 1,350 culms per ha in seventies to about 2,000 culms per ha by 2015. (ftp://ftp.fao.org/docrep/fao/010/a1243e/a1243e03.pdf.).

The annual production of bamboo in India is about 4.6 million tonnes, of which approx. 1.9 million tonnes is used by the pulp and paper industry. Their strength, straightness and lightness combined with extraordinary hardness, range in sizes, abundance, easy propagation and the short period required to attain maturity make them suitable for a variety of purposes. The economic impact of the agroforestry/farm forestry-based bamboo system may influence the general economic development considerably. The total green weight of bamboos is estimated to be 169 million tonnes in the country. Bamboos also grow abundantly in the areas outside forests with an estimated growing stock of 10.20 million tonnes. On an average, 250 air-dried culms weigh one tonne and the price per tonne of dry bamboo was approx. Rs. 1000 (auction rate) as reported by (Katwal *et al.*, 2003). latest India figures are not available. The average rate of one tonne bamboo in Madhya Pradesh during 2014 was Rs. 7000 (ICFRE, 2014)

Khan *et al.* (2007) and Hazra (2008) reported the annual yield of bamboo in natural forest of India as 2-3 and about 2 tonnes per ha, respectively. The yield in bamboo plantations is 5-12 tonnes per ha per year in drier parts of India, while well-managed plantations in China yield upto 50 tonnes per ha annually.

Due to insufficient supply of wood, especially from domestic sources, there is a need for a viable alternative material that can replace or supplement wood. Bamboo is a versatile crop which has a variety of uses and can act as economic catalyst, but only when avenues are made available for their extraction, utilization, and trading. However, consistent supply of bamboo is the main key for the growth and development of bamboo-based industrial sector. Eastern Plains contribute maximum weight (4.07 million tonnes), followed by North-East (1.07 million tonnes) and Eastern Deccan (0.09 million tonne).

The biomass of newly established bamboo plantation increases rapidly during initial six to eight years after which emergence and death of culms tend to become equal. In Assam the high annual dry weight yield is from *M. baccifera* (5 tonnes per ha) followed by the yield from *B. tulda* (3.1 tonnes per ha. The West Coast Paper Mills at Dandeli, Karnataka reported an annual yield of 3 tonnes per ha from *D. strictus* and 6 tonnes per ha from *B. bambos*. *B. vulgaris* plantations with 12m x 12m spacing yielded nearly 10 tonnes per ha per annum in Madhya Pradesh. It has been reported that afforestation of ravine lands with nursery transplants of *D. strictus* has the potential to provide the highest net annual return when compared to *Dalbergia sissoo* or *Eucalyptus* species (Gera and Gera, 2015).

Pure bamboo plantations with intensive silvicultural operations and organic fertilization can enhance the yield substantially. It has been reported that *D. giganteus* (giant bamboo) gave an annual yield of 20-30 tonnes per ha in Taiwan. The productivity of the bamboos in managed stands is much higher due to better cultivation and harvesting practices. Bamboos also produce the most biomass when managed by cultivation and selective, regular harvesting of mature culms. If harvested culms are turned into durable products, a managed bamboo forest sequesters more carbon than fast growing tree species (Kuehl and Yiping, 2012).

1.3.1 An eco-friendly material

Across the world there is a search for eco-friendly materials which can be harvested and used sustainably. The climate change threat has only intensified the search for alternatives. Individuals, institutions and governments are not only searching for new materials but also for new processes and new uses for age-old materials. Traditional items are getting 'revived' in today's context. Just to cite an example, one can see the recent spurt of interest in 'quinoa', a traditional diet item of the countries like Peru, adjacent to Andes mountains - in south America, and traditional millet varieties (jowar, bajra, ragi and many other local variants) which were until a few decades back the staple food of the Indians particularly in the low rainfall area. This coincides with the climate change challenges and erratic monsoons.

Bamboo has recently drawn much attention globally because of its remarkable properties, variety of uses and fast growth. It is closely linked with livelihoods and culture of Asian countries, including India, for thousands of years. Till 1970s, its use was widespread in the rural areas of India, but this position declined because of the increasing popularity of other materials like plastics and concrete. Bamboo also possesses characteristics that help in protecting environment. It has a high leaf surface area that makes it very efficient at removing carbon dioxide from the atmosphere and generating oxygen in its place. It produces nearly 35 per cent more oxygen than equivalent stands of trees. Certain bamboo species are known to sequester as much as 12 tonnes of CO_2 per ha (Baksy, 2013).

1.3.2 The international scenario

Bamboo is popular in almost all countries of the world, more so in developing countries, mostly due to its multifarious utility, low cost and the ease of availability. Finished high quality bamboo products are popular in Europe and North America for a variety of purposes. Since eighties, there have been many international congresses and conventions to exchange notes and strengthen scientific and technical knowledge and skills in bamboo. The International Network of Bamboo and Rattan (INBAR), is an international organization with forty-one member countries with its headquarters in China. Many of the Asian, African and South American governments are members of INBAR. India too is a member of INBAR. In India, the National Bamboo Mission (recently renamed as National Agroforestry and Bamboo Mission) has been operating from past one decade under Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi.

The post-eighties era also saw the rise of China in the world economy. Though bamboo has been used for thousands of years in all countries of Asia, China gave a new impetus to its cultivation and modernization through Chinese Town and Village Enterprises (TVE). Within a short time of thirty years (1980-2010), thousands of elegantly designed bamboo products, *viz.*, bamboo baskets, trays, hangers, bowls, and other such day-to-day use items flooded USA and other western departmental stores. The Chinese, east Asian and southeast Asian countries like Taiwan and Vietnam converted the traditional craft bamboo into an industrial product.

China and other east Asian countries have started producing 'engineered bamboo' materials in a big way. There are about twenty types of bamboo panels in the market, and China's production of bamboo flooring material is about 28 million square metres per annum. The Chinese use the engineered bamboo even for small truck bodies and other unusual usage. The size of the Chinese bamboo economy was estimated at 20 billion US dollars in 2011 (*i.e.*, approx. 1.3 lakh crore rupees) and most of the products were exported. This success of bamboo industry in China has amply demonstrated the potential of bamboo.

1.3.3 Bamboo in India

Significant interest in bamboo as a 'resource' started in the late 1990s, when India became a member of INBAR. Ministry of Environment, Forest and Climate Change, Government of India prepared an action plan for bamboo and cane sector and held a national seminar in August 1999, which was attended by a good number of policy planners, designers, architects, NGOs, government departments and botanists. The seminar brought them together to discuss all aspects of bamboo development in India (Annexure-1). The United Nations Development Programme (UNDP) started injecting substantial funds during the 1998-2004 period for development of bamboo sector and supported many government organizations like National Institute of Design, Khadi and Village Industries Commission, Development Commissioner (Handicrafts), North Eastern Development Finance Corporation Limited (NEDFi)- a Government-sponsored financial institution for North-East and a number of other agencies in the region and elsewhere. Slowly, an informal network of bamboo designers, entrepreneurs and other well-wishers emerged in the country.

Triggered by the interest shown by Government of India since 1998, the State governments in North-East started taking interest in bamboo. Tripura Government organized a big workshop in the Year 2000 and started developing a systemic approach to strengthening the bamboo sector in the State. They later set up the Tripura Bamboo Mission. Several other states followed the suite. Government of India set up two bamboo-related missions in the last decade, *viz.*, National Mission for Bamboo Applications, set up under Ministry of Science and Technology, and the National Bamboo Mission under Ministry of Agriculture–Horticulture Division, though bamboo had been traditionally looked after by the Ministry of Environment, Forest and Climate Change. This probably showed increasing interest in bamboo production and use outside forests.

1.3.4 Status report on bamboo

This status report is an outcome of the concern of the Office of the Honourable Prime Minister of India, New Delhi towards bamboo sector development in the country. The report has 4 sections comprising 14 chapters, *viz.*, (i) Introduction, (ii) Resource Overview (iii) Impediments to Growth of the Sector (iv) Silviculture and Management (v) Quality Plant Production (vi) Agroforestry, (vii) Processing and Value Addition (viii) Bamboo Products, (ix) Insect Pest and Disease Management (x) Climate Change Mitigation and other Ecosystem Services, (xi) Tools and Machinery, (xii) Legal and Policy Issues (xiii) Skill Development and (xiv) Lessons from other countries. In nutshell, the report presents the status of bamboo development, utilization and trade in India and highlights the actions required to make bamboo not only as a viable source of livelihood to farmers and artisans, but also as an item of export for the economic well being of the country. A supplement to this report provides technical details on specific aspects of bamboo for further reading.

CHAPTER - 2

RESOURCE OVERVIEW

2.1 Introduction

Bamboo finds extensive commercial use as it is a versatile natural resource. It is used to produce a wide variety of household products and also finds use in construction, agricultural applications, packing industry, etc. It is a raw material for pulp and paper industries, besides providing subsistence and livelihood to a vast rural population. Bamboos are used for manufacturing a wide range of items like furniture, trays, baskets, winnows, lampshades, fishnets, flutes, fans, mats, hats, flooring, lanterns, decoration items, pulp, plywood, activated charcoal, etc. More than 1,500 products exist, which are known to be made of bamboo. Units utilizing bamboo as a source of raw material provide opportunities for income generation and employment.

Apart from being present in forests, bamboo is grown on farmlands and homesteads in India. Bamboo covers an estimated 13.96 million ha of recorded forest area in (FSI, 2011), which is up from 8.96 million ha estimated in 2001. However, the annual yield per ha is quite low when compared to other bamboo-rich countries like China, Malaysia and Costa-Rica. Table 2.1 shows total area under bamboo and total growing stock in bamboo-rich regions of India (www.nhm.nic.in). Concentrated in North-East and central India, bamboo is found everywhere except in the cold regions of Jammu and Kashmir. *Dendrocalamus strictus* (solid bamboo in English) is the most widely grown commercial bamboo species in India.

Table 2.1: Bamboo area and growing stock in bamboo-rich regions of India

Region	Area under bamboo (%)	Total growing stock (%)
North-East	28	66
Central (Madhya Pradesh & Chhattisgarh)	20	12
Others	52	22

2.2 Information Domains

a) Bamboo has more than 1,500 documented uses, ranging from fuelwood to light bulbs, medicine to poison and toys to aircraft manufacturing. Over 1,000 million people live in houses either made of bamboo or with bamboo as the key structural, cladding or roofing element (Khan *et al.,* 2007).

b) National Agroforestry and Bamboo Mission (NABM) earlier known as National Bamboo Mission (NBM), selected Kerala Forest Research Institute, Peechi, ICFRE, Dehradun and Cane and Bamboo Technology Centre, Guwahati to host the Bamboo Technical Support Groups (BTSGs) to cater to the information and training requirements of different bamboo stakeholders.

c) Bamboo Information Centre (BIC-India) is now in the public domain (bicindia.com) with the bamboo bibliography, the directory of researchers, artisans/manufacturers and bamboo species database.

d) International Network for Bamboo and Rattan (INBAR) is the largest repository of international trade data pertaining to imports and exports statistics with commodities and partner countries reported by statistical authorities of close to 200 countries or areas and available at http://trade.inbar.int/. The data in INBAR's bamboo and rattan trade database is regularly updated, based on UN Commodity Trade Statistics Database.

2.3 Growing Stock and Production in India

The FSI (2011) inventory results (Table 2.2) indicate that the maximum number of green sound culms are found in Arunachal Pradesh (2,267 million) followed by Assam (1,723 million), Manipur (1,654 million) and Mizoram (1,587 million). Dry sound culms are found maximum in Madhya Pradesh (398 million), Rajasthan (206 million) and Arunachal Pradesh (98 million). The estimate is based on 21,089 sample plots laid in 178 districts during 2002-08. The bamboo culms and stock in areas outside forests is also estimated at physiographic zone level using the information on inventoried districts. In rural areas outside forests, the total number of culms estimated at national level is 2,127 million with an equivalent weight of 10.20 million tonnes. Eastern Plains contributed maximum number of culms (943 million), followed by North-East (289 million) and East Deccan (212 million). The equivalent weight has also been observed maximum in the Eastern Plain (4.07 million tonnes) followed by North-East (1.72 million tonnes) and East Deccan (0.97 million tonne) physiographic zones.

Table 2.2: State- and union territory-wise number of estimated culms (in million) by their soundness in recorded forests

State/UT	Green sound	Green damaged	Dry sound	Dry damaged	Decayed	Total
Andhra Pradesh	553	284	60	138	63	1,098
Arunachal Pradesh	2,267	399	98	136	80	2,979
Assam	1,723	323	95	106	94	2,342
Bihar	235	35	24	14	19	327
Chhattisgarh	331	127	33	90	20	601
Dadra & Nagar Haveli	2	1	0	0	0	3
Goa	9	1	2	2	0	14
Gujarat	93	21	22	28	7	171
Himachal Pradesh	110	50	47	57	27	291
Jharkhand	131	50	13	36	8	237
Karnataka	231	79	40	57	10	418
Kerala	95	20	17	20	5	158
Madhya Pradesh	943	286	398	421	222	2,269
Maharashtra	408	128	72	119	21	748
Manipur	1,654	381	54	138	70	2,297
Meghalaya	901	208	29	75	38	1,252
Mizoram	1,587	366	52	133	67	2,205
Nagaland	875	202	29	73	37	1,216
Odisha	489	231	47	123	54	944
Punjab	2	1	1	1	0	5
Rajasthan	390	110	206	198	122	1,026
Sikkim	182	24	9	8	5	229
Tamil Nadu	249	117	27	59	33	485
Tripura	597	138	20	50	25	830
Uttar Pradesh	94	28	43	44	26	234
Uttarakhand	98	45	42	50	24	259
West Bengal	499	69	40	19	33	661
Total	**14,749**	**3,724**	**1,521**	**2,194**	**1,111**	**23,300**

(Source: FSI, 2011)

Bamboo growing stock is a major indicator of the extent of bamboo resources. Information on the growing stock is also needed to estimate bamboo biomass and carbon content. Growing stock is normally measured in culms (for monopodial species), clumps (for sympodial species) and weight (for both types of species). Coefficients exist the different species to convert number of culms and clumps to fresh and dry weight. Commercial growing stock is calculated from the number of commercial species, the quantity of each and their physical and economic accessibility. The definition of bamboo commercial growing stock varies from country to country. Only a few countries report volume of commercial stock and the estimates vary widely, owing mostly to diverse definitions and assumptions. About 332 million tonnes of bamboo growing stock is reported by the Asian countries (Lobovikov *et al.*, 2007)

2.4 Demand

According to estimates, the total consumption of industrial wood was of the order of 60 billion cubic metres in the year 2000; such a large-scale demand exacerbates pressure on forests. In 2000, the total wood import were estimated at 20 million cubic metres. During 2016-17, the imports of sawn wood and wood in rough alone constituted 1.96 million cubic metres valued at US$ 774.7 million (DGCIS database, www.dgciskol.nic.in/). This does not include other articles of wood. Bamboo-based intermediary products can be used in composites to provide alternatives to wood such as ply-board, flooring, paper and furniture. As food alone, bamboo shoot market stood at Rs. 4.80 crore in 2001 and total international market to tap through exports was estimated at US$ 720 million.

It is estimated that around 432 million workdays are created by bamboo industries – big and small – in India alone. There are an estimated more than 25,000 bamboo-based industries. The bamboo sector employ about 20 million people, making it a source of livelihood to a large section of population, from growers, harvesters, artisans and the entrepreneurs. Around 85 per cent of the total bamboo consumed (11.77 out of 13.47 million tonnes) is used in construction, small and cottage industries, handicrafts, paper production, wood substitutes and domestic use. Tribal communities throughout India are heavily dependent on bamboos for their livelihood. According to an estimate, one tonne of bamboo is able to provide 350 man days of employment.

The Confederation of Indian Industries (CII) prepared a report in 2007, which classified various bamboo applications into:

(a) wood substitutes and composites including bamboo-based panels, bamboo flooring, bamboo furniture, incense sticks and bamboo blinds,

(b) food products- mainly bamboo shoots,

(c) construction and structural applications including traditional houses, bamboo frames with plaster and pre-fabricated houses,

(d) bamboo-based fibres and fabrics,

(e) bamboo charcoal, and

(f) bamboo for paper and pulp (Khan *et al.*, 2007). It is estimated that 13.47 million tonne bamboo is harvested annually for use in the above sectors against a demand of 26.69 million tonnes (Singh, 2008; Tripathi *et al.*, 2008).

Employment generation

- 1 tonne of bamboo provides 350 man days of employment
- 25,000 bamboo industries exist in India
- About 20 million people are involved in bamboo-related activities either full-time or part-time

Utilization of various bamboo species in India is shown in Table 2.3. Various species like *D. strictus, M. baccifera, B. tulda, B. vulgaris, O. travancorica* and *D. longispathus* are used for handicraft. Bamboo is also in demand for making bamboo briquettes as bioenergy source. These briquettes are energy efficient and have a low ash content and alkali index. The strength, properties and considerably low price of bamboo make it ideal for construction purposes like housing (especially for poor). Nowadays, bamboo huts and houses are popular in tourist resorts (CCS, 2012). The part-wise utilization of bamboos (Khan *et al.*, 2007) is given in Table 2.4. Table 2.5 gives the estimated market size of various bamboo items for 2015 (Government of India, 2003).

The demand is further poised for an increase due to various factors and the trends have been analysed (Baksy, 2013; Aggarwal, 2014). The rise in urbanization and increase in the living standards will lead to demand for furniture, and if bamboo furniture is aesthetically designed, the demand of woody bamboos will rise. Demand for bamboo as a construction material in rural housing development schemes is also expected to rise in future. It is predicted that the demand may be as high as 60 million units. As per Indira Awas Yojana guidelines, there is a need for standardizing, popularizing and replicating cost effective, disaster resistant and environment-friendly housing construction technologies, designs and materials, and bamboo, ideally suits these guidelines. Novel uses, such as, bamboo composite being used as reinforcement in cement concrete, production of bio-ethanol for mixing with fossil fuels, etc., which are emerging areas, may boost the demand further.

In the international market, the demand for bamboo flooring is expected to grow due to high levels of affluence and environmental consciousness in Europe and the USA; bamboo boards, panels and veneer are also likely to have strong demand growth, and the shortages in timber supply caused by stricter standards for wood regulation and growing preference for certification, will be met by the bamboo products, considered more eco-friendly. Bamboos find their utility in a wide variety of applications as a raw material in various products. Fig. 2.1 indicates the consumption pattern of bamboo in India.

"The lack of quality raw material (processed agarbatti sticks) at competitive prices compels the industry to import it from other South-East Asian countries like China and Vietnam"

-P.S. Sharath Babu, President, Agarbatti Manufacturers Association

Table 2.3: Utilization of various bamboo species in India

Species	Use
Bambusa bambos	Paper, house construction, panel production, fencing, scaffolding, handicraft, furniture, utensils, vegetables, medicine, fodder
Bambusa nutans	Construction, paper mat, poles
Bambusa pallida	house building, baskets, mats, toys, wall plates, screen and wall hangers
Bambusa tulda	Handicraft, paper and structure, bamboo boards, composites
Bambusa vulgaris	Pulp and paper, construction, scaffolding, fencing, handicrafts, vegetable
Dendrocalamus asper	Construction, pole, pulp and paper, edible
Dendrocalamus giganteus	House building, fencing, container, decorative items, pulp and paper, vegetable products
Dendrocalamus hamiltonii	House building construction, basket making, mats, ropes, container for water, milk and other eatables, paper and pulp, vegetables, sour drinks, pickle
Dendrocalamus strictus	Reclamation of ravine lands, paper making, construction, agricultural implements, musical instruments, furniture, food items, traditional medicines
Melocanna baccifera	House building, basket weaving, pulp, edible shoots, prefabricated walls (for partition, etc.), *tabassin,* an ancient elixir
Ochlandra travancorica	Paper, malt, baskets, umbrella handles, fishing rods, handicrafts, walls of huts, bamboo ply
Oxytenanthra parvifolia	Huts, baskets and mats

Table 2.4: Part-wise Utilization of bamboo

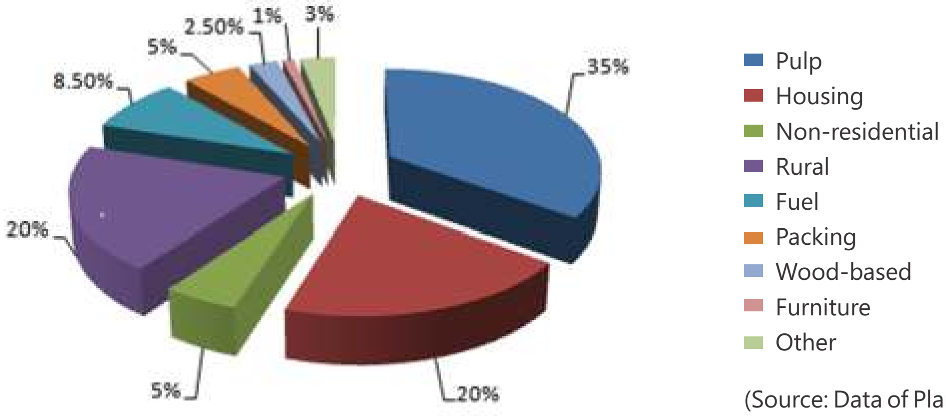
Species	Use
Wood substitutes and composites	Panels: veneers, strip boards, mat boards, fibre boards, particle boards, medium density boards, combinations of boards, composites with wood and jute, flooring, sticks for blinds and incense sticks, furniture
Food products	Shoots: processing, cultivation and packaging. Worldwide, around 200 species can provide edible and palatable shoots
Construction and structural	Traditional housing using culms, traditional barbeque houses using bamboo frame reinforced with plaster, cement or clay, pre-fabricated houses
Fibres and fabrics	Fibre for yarn is naturally anti-microbial and moisture absorbent
Bamboo charcoal	Fuel, adsorbent and a conductor

(Source: Khan *et. al.*, 2007)

Table 2.5: Estimated market size of bamboo products in 2015

Item	Market size (crore rupees)
Shoots	300
Timber substitution	30,000*
Ply board	500
Mat board	3,908
Flooring	1,950
Scaffolding	861
Housing	1,163
Roads	274
Miscellaneous (pencils, matches, etc.)	600

(Source: Baksy, 2013) ; *in 2023



(Source: Data of Planning Commission, Yes Bank Analysis cited in Bhattacharjee and Chakravarthy, 2008)

Fig. 2.1: Consumption patterns of bamboo in India

2.5 Supply

Bamboo is supplied primarily from two sources, viz., forests through State Forest Departments (SFDs) and private farms. While the government sources are inventoried and documented from time to time, no such periodic estimation is done for the private farmlands. The total growing stock of bamboo in India is 169 million tonnes. The North-East constitutes 28 per cent of the total bamboo growing area with around two-third of the total growing stock. SFDs also supply bamboo to the forest dependent communities under the nistar scheme. The average annual supply of bamboo under nistar scheme from six states, viz., Andhra Pradesh, Chhattisgarh, Gujarat, Karnataka, Madhya Pradesh and Maharashtra is around 17,400 tonnes. On an average, the annual production of bamboo is 821,363 tonnes (worth Rs. 419 crore) in the bulk bamboo producing states (ICFRE, 2010). Table 2.6 indicates the total growing stock of bamboo in India in 2012 (National Horticulture Mission, 2012). Table 2.7 shows bamboo production during 2010-2013. Table 2.8 shows estimated import-export scenario of India.

Table 2.6: Growing stock of bamboo in India

State/Region	Growing stock (million tonnes)
North-East	66.00
Mizoram	13.18
Assam	16.23
Arunachal Pradesh	11.91
Manipur	13.88
Meghalaya	5.34
Tripura	1.04
Nagaland	4.43
Madhya Pradesh	12.00
Maharashtra	5.00
Odisha	7.00
Andhra Pradesh	2.00
Karnataka	3.00
Others	5.00
Total	**66.01**

(Source: Data collected by ICFRE from States). The units of measurements are different in some States. For example in Madhya Pradesh, it is measured in notional tonnes (1 NT = 2400 running metres). In few States, it is reported in numbers while in some other States in tonnes).

Table 2.7: Bamboo production during 2010-2013

State/Region	Unit	2010-11		2011-12		2012-13		2013-14	
		Quantity	Value (lakh Rs.)	Quantity	Value (lakh Rs.)	Quantity	Value (lakh Rs.)	Quantity	Value (lakh Rs.)
Andhra Pradesh	Nos.	93,75,187	_	1,23,39,850	_	1,50,74,778	_	59,90,201	_
Chhattisgarh	NT	_	_	3,77,312	_	2,15,644	_	4,75,492	_
Goa	Nos.	1,01,250	_	42,781	_	31,450	_	67,359	_
Gujarat	quintals	12	51.80	92,251	71.96	13,534	19.88	_	_
Himachal Pradesh*	ha	416	76.23	675	29.01	508	7.38	_	_
Jharkhand	tonne	2,223	_	_	_	_	_	_	_
Karnataka	cum	33,907	_	23,587	_	2,928	_	20,599	_
Kerala	tonne	3,96,175	_	4,65,861	_	19,006	_	5,939	_
Madhya Pradesh	NT	15,554	_	-	_	_	_	79,168	_
Maharashtra	tonne	6,011	1,275.98	1,41,445	2254.03	_	_	17,982	606.59
Manipur	No.	12,58,010	5.79	9,87,652	10.427	16,42,050	16.89	21,11,420	27.469
Mizoram	No.	3,54,800	70.07	4,72,800	7.32	92,500	1.40	9,30,000	2.70
Nagaland	tonne	265	0.53	_	_	5,551	_	11,829	_
Sikkim*	ha	925	-	100	_	600	_	500	_
Tripura	No.	74,76,386	183.43	83,95,862	173.55	38,67,245	20.45	88,17,777	175.02
Uttar Pradesh	scores	99,757	65.58	63,366	50.80	_	_	_	_
Uttarakhand	score	_	_	_	_	_	_	7,214	3.78

(Source: Data collected by ICFRE from States). States follow different units of measurements, 1 NT = 2400 running metres. *These States have provided data in ha without mentioning if this is production or planted area)

Table 2.8: Estimated import-export scenario of India's bamboo products

State/Region	Import (%)	
Culms	23.22	3.51
Shoots	0.27	0.43
Charcoal	0.015	0.37
Flooring	3.25	0.16
Panels	57.18	3.68
Mats and screens	3.25	11.61
Plaits	3.91	0.52
Baskets	2.16	0.11
Pulp	2.29	0.07
Paper articles	0.01	33.00
Seats	0.17	12.20
Furniture	2.65	31.92
Total	**100**	**100**

(Source: INBAR, 2014)

Some important links for bamboo information are shown in Table 2.9, while Table 2.10 shows some other important links.

Table 2.9: Available state-wise links on bamboo information

State/Region	Link
Arunachal Pradesh	http://arunachalforests.gov.in/daporijo_forest_division.html
Assam	Assam State Bamboo Mission http://www.nbmassam.org/
Bihar	http://horticulture.bih.nic.in/
Chhattisgarh	http://www.cgforest.com/English/BambooMission.htm
Jharkhand	http://jhr.nic.in/templates/jsfdc/National_Bamboo_Mission.html
Kerala	Kerala State Bamboo Mission: http://www.keralabamboomission.org/ Kerala Forest Research Institute: http://www.bicindia.org/
Madhya Pradesh	Madhya Pradesh State Bamboo Mission http://mfp.mpforest.org/mpsbm/index.html
Mizoram	Mizoram Bamboo Developmental Agency http://mizobamboo.nic.in/
Nagaland	Nagaland Bamboo Development Agency http://nagalandbamboo.com/
Odisha	Odisha Bamboo Development Agency
Punjab	http://www.pbforests.gov.in/Bamboo_Mission.html
Tamil Nadu	Tamil Nadu Horticulture Development Agency http://www.tanhoda.gov.in/
Tripura	Tripura Bamboo Mission http://tripurabamboo.com/ http://www.tripurabamboo.com/
Uttarakhand	Uttarakhand Bamboo and Fibre Development Board http://ubfdb.org/

(Source: National Bamboo Mission, Ministry of Agriculture and Farmers' Welfare, Govt. of India)

Table 2.10: Other important links for bamboo information in India

Agency	Link
National Bamboo Mission	http://nbm.nic.in/
Indian Council of Forestry Research and Education	http://icfre.org
North-East Centre for Technology	http://www.nectar.org.in/cgi-sys/suspendedpage.cgi
Application and Research Cane and Bamboo Technology Centre India	http://www.caneandbamboo.in/
Ministry of Food Processing Industries	http://apeda.gov.in/
Agmarknet	http://agmarknet.nic.in/
Mission for Integrated Development of Horticulture	http://midh.gov.in/
World Bamboo	http://www.worldbamboo.net

(Source: National Bamboo Mission, Ministry of Agriculture and Farmers' Welfare, Govt. of India)

2.6 Shortfall in Supply

India has a supply shortfall of about 85 per cent which could be attributed to the low accessibility due to steep terrain and lack of roads, especially in north-east India, which has almost two-third of the growing stock of bamboo. Further, the estimated growing stock includes all the bamboo species, most of which are not of any commercial use. Also bamboos are often intermixed with other vegetation, rendering extraction and transport difficult task. Bringing the commercially important bamboos into domestic cultivation in non-forest areas in an intensive manner can help bridge the gap between the demand and supply.

In order to ensure a regular supply of bamboo as a raw material to industries – both small and large scale - it is essential to have a real-time database that can provide updated information on the quantity of harvestable bamboo and its prices from different zones of the country. Networking of various data sources from the Ministry of Agriculture and Farmers Welfare, Directorates of Economics and Statistics of states, Ministry of Environment, Forest and Climate Change and its organizations, etc. needs to be done for getting real time information. While SFD's can fill in data directly from where they are generated, it will be a challenge to capture data from private farmlands, community plantations and homesteads. In this case, the Directorates of Economics and Statistics of the States can play a major role through their data collection mechanism already in place. While supply side can be estimated, the demand analysis is important as many bamboo-based farms are in unorganized sector, which is difficult to capture.

The exact availability of the useful bamboos can be known only by an exhaustive species-wise resource survey using remote sensing and other inventory tools. Even among the commercially important bamboos, uniformity of the resource is lacking, as expected in any area which is the centre of the origin of woody bamboos.

"Currently, the demand of raw material far exceeds the supply"

- P.S. Sharath Babu, President, Agarbatti Manufacturers Association, Bengaluru

Table 2.11: ITC HS code of bamboo products

Code	Description
44 02 1010	Charcoal
44 09 2100	Wood continuously shaped along edges or faces, planed or not, sanded or end-jointed
44 12 1000	Plywood / veneered panels and laminated wood
46 01 2100	Plaits and similar products of plaiting materials, whether or not assembled into strips; plaiting materials, plaits and similar products of plaiting materials, bound together in parallel strands or woven, in sheet form, whether or not being finished articles - mats, matting and screens
46 01 9200	Plaits and similar products of plaiting materials, whether or not assembled into strips; plaiting materials, plaits and similar products of plaiting materials, bound together in parallel strands or woven, in sheet form, whether or not being finished articles - other articles
46 02 1100	Baskets, wickers, etc.

(Source: DGGIS database)

2.7.1 Export

Export of bamboo products from India between 2008 and June 2017 for all product codes, except ITC HS code 44121000, is given in Table 2.12. The same is illustrated in Fig. 2.2. Mass flowering (and death) of bamboo that occurred in previous years in North-East (Thapliyal, 2015) could be the reason for sudden increase in export of bamboo charcoal in 2015; this might be also true for ply and veneers export (Table 2.13 and Fig. 2.3). Reliable import data is not available.

Table 2.12: Bamboo products exported from 2008 to 2017

Year	Quantity (x 1000 tonnes)	Value (in lakh rupees)
2008	150.100	15.4348
2009	90.594	49.9385
2010	35.618	29.67558
2011	264.770	72.39873
2012	921.258	148.1287
2013	217.594	173.7030
2014	113.598	185.7832
2015	9338.358	1777.1830
2016	1202.645	459.8903
2017 (till June)	240.617	217.4340

(Source: DGGIS database)

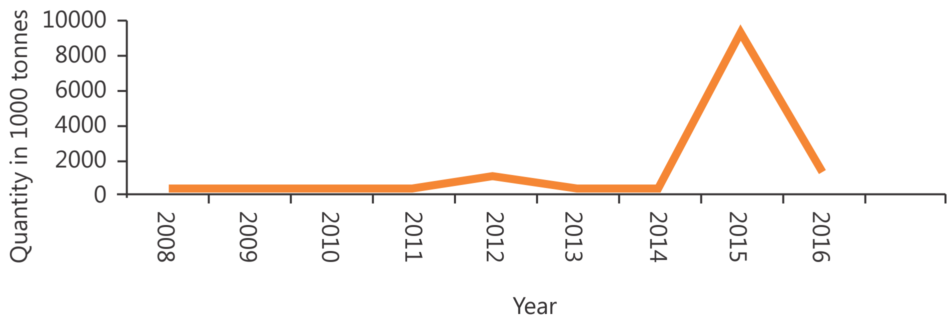


Fig. 2.2: Trend of bamboo products export from 2008 to 2016

Table 2.13: Ply and veneer products exported from 2008 to 2016

Year	Quantity (cum)
2008	40
2009	20
2010	580
2011	29549
2012	1620
2013	173
2014	2400
2015	2565
2016	457
2017	653

(Source: DGGIS database)

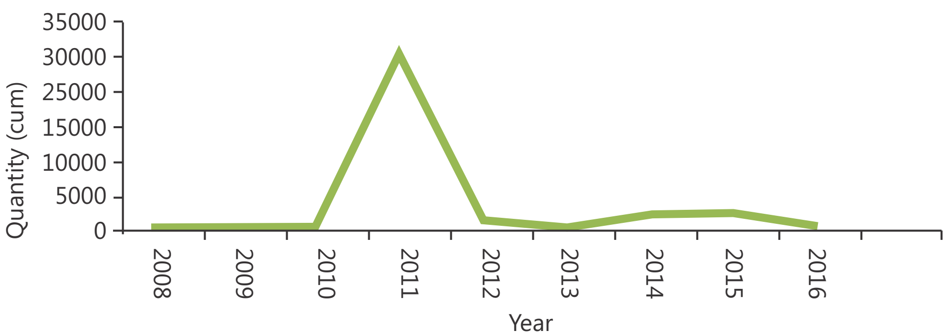


Fig. 2.3: Trend of ply and veneers export from 2008 to 2016

2.8 Best Practices

Following best practices are suggested:

a) An all-India ICT-enabled network of stakeholders in bamboo consumption and utilization to be established for sharing information.

b) Exhaustive listing of the fields of information for bamboo database including potential areas where the crop may come up (species-wise) and future estimates for setting up of industrial units on all scales – from micro to macro level.

c) Providing information on marketing and value addition along together with cost estimates. The analysis may include product-wise information on the benefits of value-addition with an aim to generate more income along with cost estimates for value-addition.

d) Periodic surveys in bamboo-rich areas need to be undertaken to keep the information updated along with future estimates for taking steps for effective policy formulation and planning.

2.9 Skill Development and Training Needs

The skills of the farmers, processors and the artisans need to be upgraded from time to time for better quality and higher level of products generation with minimum cost. Farmers should also be encouraged and motivated to go for cooperative bamboo farming system and for establishing the primary processing centres. A healthy benefit-cost analysis is a must for the long-term involvement of the farmers. Once bamboo farming is remunerative, farmers themselves will take lead in bamboo business. The current system of demand and supply assessment and market appraisal is full of flaws and is responsible for low level of progress made by NABM.

"Currently, the demand of raw material far - exceeds the availability"

- P.S. Sharath Babu, President, Agarbatti Manufacturers Association, Bengaluru

2.10 Summary

As a raw material for more than 1,500 different products, bamboo is one of the most versatile and extensively used natural resource. It covers an estimated 13.96 million ha of recorded forest area of the country. Arunachal Pradesh tops the list as it has maximum number of green sound culms (estimated to be 2,267 million) followed by Assam and Manipur. In rural areas outside forests, the total number of culms is estimated to be 2,127 million, which is equivalent to 10.2 million tonnes. Bamboo is also helpful in employment generation, with around 432 million workdays being generated in more than 25,000 bamboo-based industries that provide employment to almost 20 million people. One tonne of bamboo is able to generate 350 mandays of employment. It is estimated that almost 85 per cent of total bamboo is used in construction, cottage industries, pulp and paper, wood substitutes and other domestic uses. Around 35 per cent of the total bamboo consumed is used in pulp followed by 20 per cent in housing. Bamboo is ideal for construction (especially for poor) owing to its remarkable strength properties and low price. It is also becoming popular in building tourist accommodation in resorts. Products made out of bamboo are also traded internationally, with exports touching to almost 339 lakh rupees in the first half of 2017 and imports touching 831 lakh rupees during the same period. Bamboo is also distributed under royalty-free nistar scheme for the dependents, by six SFDs. On an average 17,400 tonnes bamboo is distributed annually.

CHAPTER - 3

IMPEDIMENTS TO GROWTH OF SECTOR

3.1 Introduction

India has the largest area under bamboo in the world. The extent of bamboo resources suggests that enough bamboo should be available in the country to not only meet the requirement of the domestic industry but also act as a major exporter. But the fact is that India is a net importer of bamboo and rattan products. The value of export of bamboo and rattan products during 2012 was only US$ 2.16 million against China's export of US$ 1,237.60 million. The monetary value of imports of bamboo and rattan products by India during this time was US$ 24.19 million. This indicates that there are some serious bottlenecks in the bamboo sector in India, which are discussed in this chapter with a view to explore the opportunities for solution.

3.2 Unsustainable Supply of Raw Material

3.2.1 Restricted cultivation

Bamboo is mostly available in forest and its extent in the agricultural land is quite limited. Planting bamboo outside the forest can be an important and plausible alternative towards increasing the availability of bamboo.

3.2.2 Low productivity: silvicultural factors

The yield per ha of bamboo in India is very low in comparison with other countries such as Japan, China, Taiwan and Malaysia. India's productivity is one-fourth to one-fifth of China and Taiwan (Hazra, 2008). The estimates of bamboo productivity in India are quite variable. Gera and Gera (2015) have reported 1 tonne per ha average annual productivity of bamboo in natural forests in the country. Khan *et al*. (2007) put the average yield for bamboo grown in India at 2-3 tonnes per ha per year. Hazra (2008) reported that the annual yield of bamboo varies around 2 tonnes per ha, depending on the intensity of stocking and prevailing biotic interferences. The yield in rainfed areas can be increased 4 to 5 times in five years if protection from grazing and fire is ensured and proper management practices (soil working, fertilisation and thinning) are adopted (Lakshmana, 1993).

Bamboo yield in plantations is 5-12 tonnes per ha per year in the drier parts of India; well-managed and technology-based *Dendrocalamus strictus* plantations yield 10 tonnes per ha per year (http://keralaagriculture.gov.in/htmle/bankableagriprojects/fw/Bamboo.htm). The maximum yield obtained from plantations in India are in the range of 10-15 tonnes per ha while well-managed plantations in China yield up to 50 tonnes per ha (Hazra, 2008).

Natural forest is the major source of bamboo in the country. Due to the extensiveness and remote areas, bamboo in the forest is not subjected to required care or cultural treatment. Besides poor management, these areas also suffer from heavy damage due to grazing, illicit removal, fire, etc. Large gaps, present in the open forests, lower the production. Bamboo clumps in many locations, especially remote localities, are heavily congested. High temperature coupled with aridity (during summer season) creates moisture stress conditions over larger part of India, which manifest in lower productivity.

In a number of States, bamboo extraction from forests is done through contractors. In the absence of close supervision during extraction, the contractors tend to carry out bamboo extraction unscientifically without caring for regeneration. The damaged clumps are not able to produce good quality culms thus, lowering the quality and the yield.

3.2.3 Low productivity: genetic interventions

Low productivity of bamboo can also be attributed to non-availability of genetically superior planting material. Genetic improvement of bamboo is presently in early stages of research. Phenotypically superior material has been collected. Evaluation of the genetic superiority on the basis of multi-location field trials followed by multiplication of superior material would requires significant length of time before large-scale planting. Concurrent testing and multiplication of promising material can be an effective and plausible alternative (Kumar and Singh, 2001).

"Getting adequate quantity of seasoned and treated material for construction has been a major impediment in bamboo architecture"

- Neelam Manjunath, Propritrix, Manasaram Architects, Founder and Managing Trustee, Centre for Green Building Materials and Technology (CGBMT), Bengaluru

"Lack of modern technology for conversion of bamboo to industrial products of international quality limits the growth of bamboo sector"

- V. Renganathan. MD, Pointec Pens and Energy Pvt. Ltd., Bengaluru

3.2.4 Limited availability

Apart from the unfavourable site conditions and inadequate care, over-indulgence in conservation-oriented approach is indirectly leading to sub-optimal current yields of bamboo besides degradation. Thus, bamboo removal in India is very low considering the area and growing stock of bamboo and size of user groups in the country. The low removal explains shortage of bamboo for artisans and industry in India, despite having the world's largest area under bamboo. It is also clear from this account that bamboo stock in the country is large enough to meet the needs of a formidable bamboo industry.

It is, however, accepted that area under bamboo in India represents not only pure bamboo forest, but also areas where it is a major associate species. This holds good for other countries too, albeit to different degrees. Unlike trees, bamboo is a plant that responds positively to periodic removals. Scientific silvicultural practices recommend harvesting of bamboo in green condition at cutting cycles of 3 to 5 years. Over-maturity results in drying of culms leading to degradation of the clump and decline in yield.

Non-extraction of silviculturally removable culms might be one of the most important factors responsible for lower growing stock per unit area as compared to many other countries.

Bamboo removal in India is only 1 per cent of China despite having 208 per cent greater bamboo area than China and almost an equal population to support *vis-à-vis* China. The growing stock in India is 74.3 per cent of China (Table 3.1).

Table 3.1: Bamboo resources and annual removals in Asia

Country	Area (x1000 ha)			Growing stock (million tonnes)			Removals (x1000 tonnes)		
	1990	2000	2005	1990	2000	2005	1990	2000	2005
China	3,856	4,869	5,444	96	144	164	2,60,000	6,10,000	12,30,000
India	10,711	10,863	11,361	115	117	122	NA	NA	14,615
Indonesia	2,151	2,104	2,081	13	11	10	44	215	NA
Malaysia	422	592	677	7	10	11	10	4	NA
Myanmar	963	895	859	18	18	18	7,753	8,481	9,803
Pakistan	9	14	20	0.09	0.14	0.21	61	55	136
Bangladesh	90	86	83	1	1	1	993	NA	NA
Thailand	261	261	261	NA	NA	NA	NA	NA	NA
Vietnam	813	813	813	NA	NA	NA	NA	NA	NA
Philippines	127	156	172	6	6	6	16	19	21
Sri Lanka	3	3	3	NA	NA	NA	271	1000	1500
Japan	149	153	154	NA	NA	NA	200	60	40

(Source: Lobovikov *et al.*, 2007)

Domestic users require very small quantities of bamboo, which should be supplied from local forest as a matter of traditional right. They also obtain raw material from home gardens, backyards, etc. of their own as well as nearby households. Manufacturing units can be broadly classed as micro, small, medium and large enterprises. Their raw material needs increase with scale of operation.

The Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 (or the Forest Rights Act) vests the forest dwelling communities with the right of ownership and the right to collect, use and trade bamboo, since Forest Rights Act recognises the traditional rights, the industrial development gets restricted as the rights are vested with the forest dwellers.

Poor productivity is one reason that results in insufficient supply of raw material to industries. Faulty sale procedure for bamboos causes unequal distribution of raw material to artisans and industry. The priority needs to be given to artisans / rural communities for making handicrafts, etc, where the requirements are generally small as compared to industries. There are reports that some states allow drying of culms as a standard practice for supplying bamboo specifically to pulp and paper industry, that too at subsidized rates, which are a fraction of the rates charged from local people. Bamboo was wiped out from four districts of Madhya Pradesh to supply bamboo to one paper industry (Saxena, 2004). As an example, the West Coast Paper Mills was awarded bamboo at the rate of Rs. 3.12 per tonne of paper, or about Rs. 1.50 per tonne of bamboo-less than 0.1 per cent of the market price (Saxena, 1999). Loss of productivity and sale to a large industry at subsidized rates is a huge economic loss with ecological ramifications. It has socio-economic dimension too as it deprives the local artisans of raw material for earning their livelihood. The National Forest Policy, 1988 mandates that industry should obtain raw material supplies from outside the forest.

Handicrafts, furniture, structural usage, composites, incense sticks, textile, etc. are high value-addition industries while pulp and paper, biofuel, etc. do not add much value to bamboo. Challenge lies in promoting high value-addition enterprises; this in many cases may take place even by sacrificing the interest of low value-addition bulk processing industries.

3.3 Low Consumption and Demand

It is generally believed that there is a shortage of demand for bamboo products in the market. However, there is a contrarian view stating that the industry is not able to meet the present level of demand for bamboo products. The root cause is the limited availability of harvested bamboo. According to an estimate, the total annual demand for bamboo in India is 27 million tonnes while supply is only 13.5 million tonnes. The balance demand is met from imports. The world bamboo market size is about US$ 20 billion, which is dominated by exports from China. India imported pulp, newsprint, plywood, paperboard, wood and wood products worth US$ 68.09 billion during 2015-16. Bamboo has multiple utility and can substitute for several of the above-mentioned commodities in the import basket of India, besides providing environmental benefits and improving livelihood of the poor and backward people in remote areas of the country. India can be a net exporter of bamboo, earning huge foreign exchange.

3.3.1 Inadequate market network and linkages

Underdeveloped market: There is a general communication gap among, sellers, buyer and manufacturers as also the lack of promotion of bamboo product in the market. The disconnect between the markets and industry/product is quite prominent togeter with inadequate linkages between the producers, industry and the consumers. This leads to high production and transportation costs.

3.3.2 Absence of quality standards/assurance and branding

The following reasons can be ascribed to the limited demand of bamboo and bamboo products in the country :

a) Poor quality product: Due to use of untreated bamboo in production process, the durability of the bamboo products becomes an issue, which adversely impacts demand for bamboo products.

b) The design and aesthetics are usually not up to the mark to generate and sustain demand even in the domestic market.

c) Lack of branding: Presently there is no branding for bamboo products in India. The large and premier retailers do not market these products on a large scale. The capital infusion required to boost bamboo sector is thus missing.

3.3.3 Poor awareness

Unfavourable perception of consumer: Bamboo products are perceived to be of low quality. Hence, they prefer wood products and are reluctant to purchase bamboo products. The Indian middle and upper classes are still not fully exposed to the superior quality and high-end bamboo products. They have deeply ingrained perception that bamboo products are low in quality and/or durability.

3.4 Production Constraints

With almost 30 per cent of the world's bamboo resources, India has only about 4 per cent share in the global market because of the minuscule industrial share. Owing to the various constraints in production, the cost of bamboo products produced in the country is substantially higher than competitors. Bamboo-based industry in India is under-developed and uncompetitive in international market. The industrial production is further threatened with cheaper and growing imports.

3.4.1 Isolated industries

- Fragmentation of industry: Bamboo-based industry is dominated by small firms with very limited forward and backward linkages.
- Multi-tasking by industry: Manufacturers are required to do multi-tasking as they do primary and secondary processing themselves before making their intended product. Due to continuous engagement in sundry activities, industries are not in a position to develop expertise in developing and producing specialised products. Because of the lack of market linkages, firms are required to handle most aspects of the processing chain themselves. This results in inefficient use of machinery, labour, space and other inputs.

3.4.2 Uncompetitive products manufacture

- Poor quality supplies: Bamboo harvested by cultivators is supplied to aggregator middlemen. The middlemen do little grading and sorting, and supply it to the industry. Harvesters and middleman generally do not care about the quality bamboo. Material arriving at an industry is poorly graded; hence, wastage is very high-sometimes as high as 50 per cent. There are no takers for unused material emanating from an industry.
- Low volumes of supplies: About 44 per cent of the total cultivated bamboo is utilised in the paper and pulp industry and in scaffolding for construction mostly without any value-addition. Other users face continuous shortage of bamboo, especially of required grade and or species.
- Lack of access to inputs in production: Production units are mostly located near bamboo forests away from the market. The availability of electricity, water and other raw materials remains uncertain especially in distant places where these units are located. Incense stick production is an important use of bamboo. However, local value addition does not take place in the places of production of sticks due to unavailability of other ingredients.
- Small scale of operation: As industrial units are small, their scale of production is small and production process is slow this does not allow meeting large supply orders. Small-scale production rules out the benefit of economies of scale. This renders the cost of production high.
- Premium products of bamboo such as flooring can compete with wood. Due to high environmental cost of metals and other conventional building materials, bamboo with its high tensile strength can serve as an eco-friendly material in several construction activities. Bamboo strand lumber is an alternative to conventional timber and should be promoted as an environment-friendly proposition because of the fast renewable and multiple-cropped nature of bamboo clumps. Its durability, aesthetics and mechanical properties also make it a viable alternative for conventional timber.

Emphasising the importance of an effective value chain, Baksy (2013) cited the example of some industries preferring to buy imported bamboo at around Rs 75-80 per kg, rather than buying domestic bamboo at Rs 50-56 per kg. The imported bamboo was received as semi-processed bamboo sticks, allowing the industries to focus on their production rather than on processing of the bamboo culms. On the other hand, manufacturers utilising domestic bamboo had to utilise unsorted bamboo poles with as high as 50 per cent wastage due to poor quality, and then go for further processing.

3.4.3 Poor product quality

Poor quality product: The durability of the bamboo products becomes an issue where untreated materials are used. The concepts of design and aesthetics are not given due importance, which prevents acceptance and growth of bamboo even in the large domestic market. Often the domestic bamboo products are not as per the latest trends of design and utility to suit the present lifestyle. Absence of standardisation: The absence of quality standardisation in bamboo sector leads to variability in quality of products. This adversely impacts saleability of the produce, especially in the international market.

3.4.4 Lack of trained manpower

Lack of trained labour: Traditional skills employed by the artisans do not allow industry-level production speed, scale and the quality. The industry is dependent on untrained workers with poor efficiency and techniques. Small scale of operation does not allow economic incentive to the industry to train manpower in industrial processes at research and training institutions.

3.5 Inadequate warehousing facility

The premier retail chains do not stock bamboo products. If they somehow store such products, they often incur losses due to poor demand.

3.6 Backward and Forward Bottlenecks

Backward production linkages are the linkages from the bamboo sector to the part of the non bamboo sector that provides inputs for bamboo production and utilization. Forward production linkages refer to the part of the non-bamboo sector that uses bamboo output as an input.

"Lack of skilled bamboo technicians and training schools are among the major factors affecting growth of bamboo sector."

- V. Renganathan. MD, Pointec Pens and Energy Pvt. Ltd., Bengaluru

3.6.1 Discouraging tax regime

Bamboo sector was exempted from VAT for the past 12 years. Under the GST regime taxes have been imposed on various bamboo products ranging from 4 per cent on raw bamboo to 28 per cent on some finished products. Bamboo plywood, mat boards and bamboo boards are taxed at 18 per cent bracket of tax whereas other similar products get different treatment;. particle boards/bagasse boards/rice husk boards, etc. are taxed at 12 per cent. Musical instruments are taxed at 28 per cent. Bamboo flooring is taxed at 18 per cent. Handicraft items, which were exempt from tax earlier are now taxed at 12 per cent (Table 3.2). This will adversely affect the bamboo sector which includes poor and marginalised segment of the society.

Table 3.2: GST rates on bamboo products

S. No.	Category	GST rate (%)
1.	Charcoal (wood and bamboo)	Nil
2.	Musical instruments (indigenous handmade)	Nil
3.	Medicinal products of bamboo (unprocessed)	5
4.	Bamboo vegetable products	5
5.	Bamboo mattings	12
6.	Handicraft items	12
7.	Bamboo plaits / baskets/ wickerwork, etc.	12
8.	Medicinal products of bamboo (processed)	12
9.	Bamboo mat boards	18
10.	Bamboo plywood	18
11.	Bamboo flooring	18
12.	Activated carbon (all types including bamboo)	18
13.	Musical instruments (others)	28

(Source: http://www.allaboutbamboo.org/2017/07/indias-gst-and-bamboo-sector.html)

3.6.2 Unfavourable exim policies

Basic import duty on round bamboo sticks, which was earlier 30 per cent, had been reduced from 30 to 10 per cent in the past few years. While the transportation cost for incense stick from Tripura to Chennai was 8 paisa per kg, the transportation cost from Malaysia and Vietnam to Chennai declined to 1 paisa per kg. As a result the Rs. 6,000 crore agarbatti industry became majorly dependent on imports; the cottage industry, which continued to use domestic bamboo sticks became uncompetitive resulting in job losses to a very large number of people (Times of India, 2013).

3.6.3 Weak market mechanisms

Bamboo sector suffers from weak forward and backward linkages. Some of the major issues related to linkages are:

- Long distances between production units and consumption centres often increase the transportation cost of the finished products.
- Units are unaware of the requirement of the domestic and international markets. The industry is caught in a vicious cycle where large buyers do not come to the industry due to lack of information about the majority of producers and the producers do not produce on a larger scale for not having bigger orders.
- A network of bamboo market is lacking which would connect bamboo growers, culm buyers, processing industries, manufacturers, wholesalers, middlemen, retailers, buyers and international market.
- Unlike agriculture sector, assurance of fair price is not available in the bamboo sector. This kind of support is a pre-requisite for the development of a strong bamboo sector.
- Credit facilities available for agriculture and allied activities are not uniformly available for bamboo sector.

3.6.4 Inadequate infrastructure

Bamboo sector also suffers from inadequate infrastructure. Shortage of water, electricity and chemicals, non-availability of improved tools, equipment and machinery, etc. have adversely affected the sector. Modernization of infrastructure to develop high quality products with good durability is needed. Modern tools and technologies need to be integrated in bamboo industry right from the handicrafts to construction use. The necessary infrastructure need to be developed in the form of bamboo industrial clusters to allow sharing of infrastructure and other resources for enhanced production capacity at competitive rates. Unorganised bamboo sector needs to be organised modernized and updated to compete with the global trends of bamboo products.

3.7 Insufficient Research Support

Bamboo has received less research and development support in India compared to countries like China. The sector requires more research and development support. however, adequate level of research backup is already available to scale up in to a strong industry.

3.7.1 Productivity

Problems of low productivity and non-availability of superior planting material have already been discussed under other heads in this chapter.

3.7.2 Technologies

There is need to develop and upgrade the technologies for bamboo industries for making latest products with higher durability.

3.7.3 Hurdles in processing and structural product manufacture

A major drawback of using bamboo in paper manufacture is its high silicon content. About 60 per cent of the ash content in non-wood materials is SiO_2. Pulp and paper making processes such as material preparation, digester operation, brown stock, chemical recovery system, recausticising and paper machine operations are adversely affected by the presence of silica in bamboo. Also, there are some physiological constraints of using bamboo in pulp and paper industry, which include the following (Rowell *et al.,* 1997):

- difficulty in chipping due to hollow stem,
- difficulty in mechanical handling because of variable diameter and crookedness of stem,
- presence of dense nodes which are highly lignified and difficult to pulp, and
- high percentage of parenchyma cells.

Besides, bamboo has the disadvantage of low fibre and pulp yield per ha per year in comparison to other raw materials used (Table 3.4).

"Government support for R&D projects is very limited and there is no industrial tie-up worth mentioning"

- Mahadev Chikkanna, Director, Spectalite, Spectrus Group, Bengaluru

Table 3.3: Raw material used for paper making

Raw material	Fibre yield (tonnes/year/ha)	Pulp yield (tonnes/year/ha)
Fast-growing softwood	8.6	4
Fast-growing hardwood	15	7.4
Wheat straw	4	1.9
Rice straw	3	1.2
Bagasse	9	4.2
Elephant grass	12	5.7
Canary grass	8	4
Bamboo	4	1.6

(Source: Pierce, 1991)

These constraints, from both physico-chemical and economic perspectives restrict the usage of bamboo in pulp and paper making. Bamboo plant produces cyanoglycosides and a corresponding hydrolytic enzyme (beta-glycosidase). On cell disruption it breaks down to a sugar and a cyanohydrin, which rapidly decomposes to hydrogen cyanide (Anon., 2004). The cyanogenic glycosides content of bamboo shoots of different species is reported to be 67 to 8000 mg/kg. Also, homogentisic acid is responsible for a disagreeable pungent taste of bamboo shoot (Bhargava *et al.*, 1996). The acute lethal concentration of hydrogen cyanide for human beings is reported to be 0.5–3.5 mg/kg body weight (EFSA, 2004).

3.8 Capacity and Skill Handicaps: Unskilled Manpower

Capacity building is required in the fields of bamboo resource management, processing, utilization, value-addition and marketing. The present focus of capacity building programmes in bamboo is not sharp. Very few capacity building programmes are conducted *vis-à-vis* the large bamboo-dependent population. The target population is mostly unaware of such programmes. The programmes are usually conducted far away from their places of living, training fees and other costs are unaffordable; use of visuals is inadequate for easier comprehension; and the language used for training is occasionally alien to them. Training programmes focus merely on raising nursery and plantation and ignore the other areas (due to lack of technical expertise of trainers), which are probably more important from point of view of bamboo enterprise. Trainees are unable to make use of training due to limited opportunities around them.

3.9 Legal and Policy Neglect

3.9.1 Harvest and transit rules

Restrictive harvest and transit regime is a serious handicap in supply of bamboo to the artisans and industries. Bamboo is classed as 'tree' in the Indian Forest Act, 1927. Harvested bamboo is, therefore, classed as a 'timber' and therefore, is subject to rules similar to commercial timber trees. This is identified as a hurdle in promoting cultivation of bamboo outside forest. Thus, even if a huge bamboo resource is available in the country, much of it remains unutilised. Ban on green felling imposed by the Supreme Court of India in 1986 above 1000 m altitude in the Himalaya is also a factor restricting harvest of bamboo in the hills.

Extensive studies are imperative on the impacts of no-harvest in different types of forests. Transit rules for bamboo vary with States. In some of the states, rules vary with districts and species. Many states, through legislations, have exempted specific forest produce (including bamboo) from transit regulation under Section 41(3) of the Indian Forest Act. However, the regulations need to be harmonised across the States. Rules governing harvest and transport of bamboo by forest dwellers (in forest), farmers (in agricultural field) and other land owners (in community land and other private, institutional, government and wastelands) need to be amended and simplified to reduce the bottlenecks and time involved in getting permission for harvest and transit. However, recently Ministry of Environment, Forest and Climate Change (vide F.No. 9-1/2016-FP (Vol.2) dated October 9, 2017) amended Section 2(7) of the Indian Forest Act, 1927 allowing pan-India transit permit for movement of bamboo. This is expected to overcome hardship faced by farmers and traders moving bamboo/ bamboo products across the country. Procedures may be further streamlined to overcome rough edges, if detected, during implementation.

"Due to lack of warehousing and storage facilities at a centralised location, it is very difficult to source material for meeting the needs of construction industry"

- Neelam Manjunath, Propritrix, Manasaram Architects, Founder and Managing Trustee, Centre for Green Building Materials and Technology (CGBMT), Bengaluru

"The growth of bamboo industry is dependent on understanding the needs of both the industry and the farmers and each of these should be addressed separately and precisely"

- Dr. Muyeed Ahmed, Project Coordinator, PoinTec Pens and Energy Pvt. Ltd., Bengaluru

3.9.2 Governance

Over past three decades, the primary objective of the forestry sector has been shifted from production to conservation. Reorientation of the priorities would help in sustainable utilisation of forest resources. However, this one-sided and traditional view is coming in the way of realising the full potential of bamboo as a resource that is capable of socio-economic transformation, besides improving the quality of forests. Bamboo, therefore, needs to be declared as a priority sector.

3.9.3 Multiple owners

- Bamboo as a resource is governed by policies and laws pertaining to different ministries, viz. Ministry of Environment, Forest and Climate Change (forest laws-e.g. Indian Forest Act, 1927, Forest Conservation Act, 1980), Ministry of Tribal Affairs (Forest Rights Act,2006) and Ministry of Agriculture and Farmers Welfare (National Bamboo Mission). The National Bamboo Mission could not achieve the desired results and there was proposal to incorporate it into the National Mission on Oilseeds and Oil Palm. Presently, it has been reoriented into National Agroforestry and Bamboo Mission. (NABM) under the Department of Agriculture Cooperation and Farmers' Welfare of the Ministry of Agriculture and Farmers Welfare, Govt. of India. The Ministry of Environment, Forest and Climate Change is also one of the important stakeholders with claim on the bamboo sector.
- There is lack of coordination among these organizations leading to contradiction and confusion in the implementation of laws and policies. In the absence of a single governing body, the full potential of the resource cannot be utilized.
- Bamboo is an integral part of India's forests and covers 13.96 million ha area, which is 18.14% of the recorded forest area of the country. The extent of area and growing stock of bamboo in farmland is, and will always remain, a very small fraction of that in the forest. The nature of produce (not the place of its artificial production) determines whether a produce belongs to one sector or the other. Bamboo, therefore, is essentially a forest crop (not an agricultural crop) and yields a forest produce (not agricultural produce). Bamboo is a perennial plant; thus, bamboo planting is a short time activity and the major time and effort of a bamboo grower or manager is spent on managing this forest produce in close coordination with forestry sector. Distancing bamboo sector from forestry sector, therefore, does not seem to be in the interest of bamboo sector.

3.10 Lack of capital investment

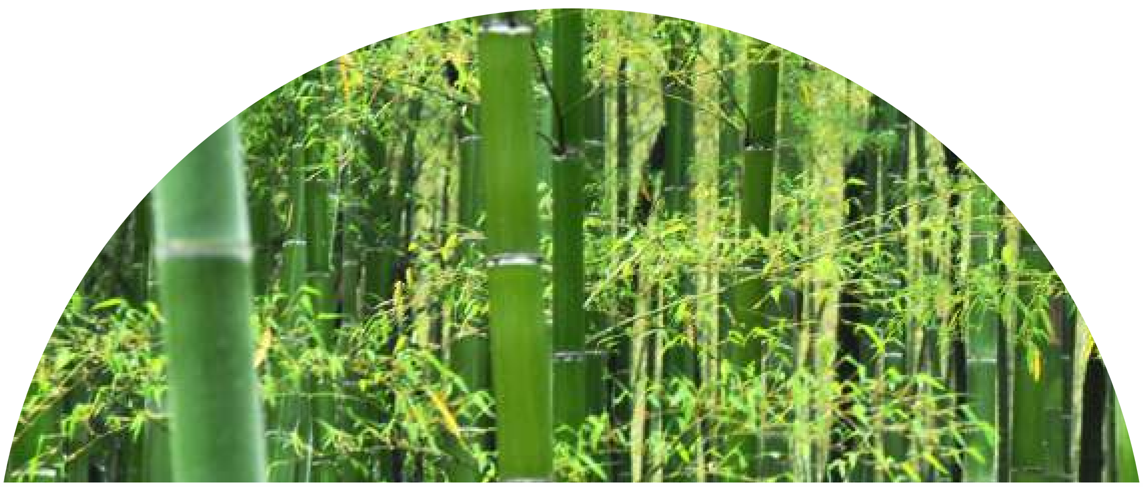
The bamboo sector is seriously handicapped by lack of capital investment. The major investment has to come from the private industry. Presently, the manufacturing is largely dominated by households who treat it as a part-time activity to supplement their income and lack motivation and capability to scale up their operation. Few households and self-help groups take up bamboo processing as a full-time activity but are limited by financial and technological constraints. Traditional tools are used to make handicrafts and furniture items. Paper-industry is reasonably strong in India, but paper manufacture is a low-value and bulk processing activity with low rates of pro-poor financial impact and employment generation. The number of firms that produce new-generation premium products of high quality for domestic and international market, is very meagre.

The industry needs an encouraging business environment to invest in this sector. Assured raw material, land, infrastructure, credit, and a favourable regime of import-export rules and policy support, require to be provided through a speedy and transparent system. Much of the state-of-the-art equipment in primary and secondary processing would have to be imported, until its development and manufacturing in India itself, to undertake production of premium products at competitive cost. Industrialists must be invited and encouraged to invest capital, import/manufacture tools and machinery, set up industrial clusters as well as individual units, and participate at all suitable levels in the value chain. The problems in this direction have to be addressed in a holistic way. The industry, therefore, needs to be involved in planning process for development of the sector.

3.11 Conclusion

Lack of capital investment by industry, sub-optimal harvests, restrictive harvest and transit rules, fragmented value chain and disconnect from international market are the five biggest factors obstructing the growth of the bamboo sector.

The five biggest hurdles in development of the bamboo sector are lack of capital investment by industry, sub-optimal harvests, restrictive harvest rules, fragmented value chain and disconnect from international market. Inadequate capital investment is the manifestation of an unfavourable business environment and policy regime surrounding the bamboo sector. Non-availability of modern tools and machinery, small-scale production, unsorted raw material supplies, multi-tasking by industry, inadequate warehousing facility, untrained manpower and inadequate tax incentives. render our bamboo industry uncompetitive in international market. Inadequate market promotion, absence of quality standards, poor perception of public and communication gap among stakeholders are responsible for deficient demand. Low bamboo productivity and faulty sale procedure also create shortage of raw material, especially harming the artisans. Uncoordinated steps by multiple regulatory ministries are not allowing improvement of the sector.



SECTION-II
Status of Research and Development

CHAPTER - 4

SILVICULTURE AND MANAGEMENT

4.1 Introduction

Bamboo is a renewable resource that grows at a very high rate. It is extremely versatile in its adaptability and utility, and has great relevance for ecological, socio-economic and industrial development. The supply of bamboo is inadequate to meet the present demand of artisans and industry in the country. To sustain the industry and boost exports, it is imperative to increase area under bamboo and also restock the degraded bamboo areas. Bamboo productivity in India is quite low in comparison with China and other major bamboo-growing countries. Regeneration of forests and planting bamboo in non-forest areas with superior genetic material provides an opportunity to improve the productivity and expand the bamboo-cultivation area, thereby augmenting bamboo resources in the country. Planting and managing bamboo requires an understanding of growth behaviour, site requirements, adaptability, silvicultural characteristics, seed, nursery and plantation technologies, tending and extraction methods.

4.2 Growth Habit and Morphology

The growth form of bamboos varies from a few centimetres to 35 m in height with large, medium sized to thick, sometimes thin-walled culms. Depending on the growth form, bamboos may be classified into four main types, i.e., tree form, reed form, shrub form and straggler form (Table 4.1). Most bamboos in India are of tree form category. The reed forms are small- to medium-sized bamboos with long internodes. They are found growing gregariously alongside streams or rivers as reed brakes. The shrub forms are short and erect with very thin culms, up to 5 m in height and are usually found at higher elevations in the Himalaya near snow line and also in higher reaches of the Western Ghats. The straggler bamboos, also called climber bamboos, are not common in India.

Table 4.1. Examples of different forms of bamboo

Form	Species
Tree	*Bambusa bambos, Dendrocalamus strictus, B. balcooa, B. nutans, B. tulda*
Reed	*Ochlandra travancorica, O. scriptoria, O. rheedi*
Shrub	*Arundinaria racemosa, Sinoarundinaria falcata*
Straggler	*Dinochloa andamanica, Melocalamus compactiflorus*

Bamboo can be typically described as a fast growing woody grass with an extensive underground network of rhizomes and fibrous roots. Above the ground, a stem (culm) arises from rhizome which is normally a hollow cylinder tapering towards the top. The emerging culm, called shoot, is protected by sheaths, which stay on till the culms develop fully. The size and shape of the sheath is typical of the particular bamboo species. The growing rhizome is protected by a sheath, which is normally not visible, and the fibrous roots extend from the nodal portion of rhizome. Most bamboos flower and fruit once in their lifetime, either sporadically or gregariously.

A bamboo plant typically consists of four main vegetative parts: (i) rhizome (ii) roots (iii) culm (iv) branches

The rhizome, culm and branches are segmented by solid node portion while the internode is mostly invariably hollow, though there are notable exceptions like *D. stocksii*. Nodes are protected by sheath and are the key growth points from which other vegetative parts develop and grow. Roots are not segmented nor do they have protective sheath. The rhizome is the underground portion of the bamboo and serves as the foundation base. It grows typically laterally under the soil surface resulting in lateral expansion of the bamboo clump. Rhizome also acts as a food reserve contributing to growth and vegetative reproduction. The thin fibrous roots emerge from nodes in rhizome and forage for moisture and nutrients while new culms emerge upwards from the buds in the rhizome. Three distinct types of rhizomes (Fig. 4.1) are recognized, which influence the aboveground growth characteristics of bamboo (NMBA, 2005).

(a) Monopodial rhizome

This is a typical non-clump forming horizontally growing rhizome best described as runner. Here, one axis is dominant, *i.e.*, rhizome and secondary axis culms develop from the lateral buds in runners, e.g., *Phyllostachys edulis* (moso bamboo), etc.

(b) Sympodial rhizome

This is a typical clump forming rhizome in which each rhizome is dominant and secondary culms develop from it, e.g., *B. bambos, D. strictus,* etc.

© Amphipodial rhizome

Some bamboos, e.g., *Guadua angustifolia, M. baccifera* (muli bamboo), etc. have rhizomes that have traits common to both monopodial and sympodial and can be described as amphipodial.

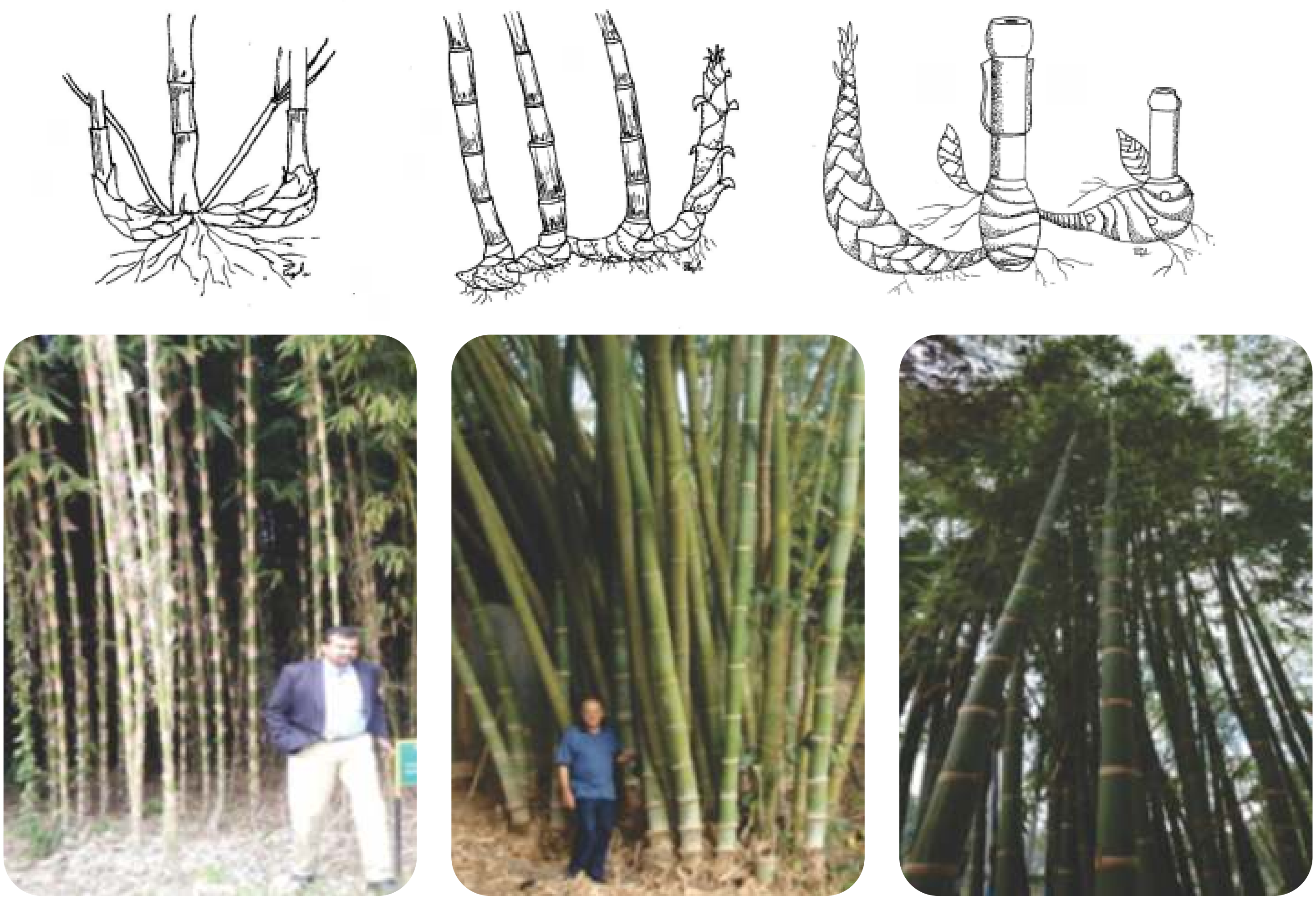


Fig. 4.1: Culms of *M. baccifera* (monopodial), *D. brandisii* (sympodial) and *G. angustifolia* (amphipodial)(from left to right)

Flowering cycle of some bamboo species

The flowering cycles of most of the important Indian bamboo species are about 40-50 years. Flowering cycles of some species are: (i) *Bambusa balcooa*: 35-45 years, (ii) *B. bambos:* 45 years, (iii) *B. tulda:* 30-60 years, (iv) *Dendrocalamus giganteus:* 40 years, (v) *D. hamiltonii:* 30-40 years, (vi) *D. longispathus:* 30-32 years, (vii) *D. strictus:* 25-45 years, (viii) *M. baccifera:* 40-45 years, (ix) *Ochlandra ebracteata:* 7 years, (x) *Phyllostachys bambusoides:* 120 years, (xi) *Sinarundinaria wightiana:* 1 year, and (xii) *Thyrsostachys oliveri*: 48-50 years (Thapliyal *et al.,* 2015).

Fig. 4.2: Natural variation in bamboo seed size (top row, from left) *D. brandisii, B. tulda, M. baccifera,* (bottom row, from left) *B. bambos. D. strictus* and *Schizostachym* dullooa

4.3 Silvicultural Practices for Bamboo Management in Natural Forests

Only the mature culms are cut and extracted. The culms are classified on the basis of age, *i.e.*, one-, two-, three- or four-year- old. Regeneration is through new culms produced annually from the underground rhizomes; this relatively simple practice is followed everywhere regardless of the species or type of forest. After gregarious flowering, usually at long intervals depending on type of species, the culms dry up and die and natural regeneration is then ordinarily from seeds. Silvicultural practices of bamboos growing in natural forest depend on the habit and rooting behaviour, i.e.. whether it is monopodial or sympodial type.

4.3.1 Silvicultural systems

Both clearfelling and culm selection felling are the silvicultural systems commonly employed in natural bamboo forests. The practices vary slightly according to the growth habits of the type of bamboo. With sympodial (clump-forming) bamboos, the clump itself is the working unit upon which thinning, tending or harvest cuttings are applied. In the monopodial (non-clump-forming) group of bamboos like *M. baccifera,* the regeneration area is similar to that of a natural forest with single scattered culms forming the working stock over a suitable cutting area.

Culms, if left unharvested for a long time, begin to deteriorate and decay thereby reducing their economic value.

(a) Culm selection system:

In both monopodial and sympodial bamboos, under the selection system, the mature culms are cut on a short felling cycle of three to five years. Generally, the larger species like *D. brandisii and B. bambos,* require a longer time to reach the harvesting age depending on the health of rhizome. Culms if left unharvested for a long time start to deteriorate and decay, thereby reducing its economic value. Silvicultural interventions like tending, decongestion, extraction and removal of defective culms, selective extraction, etc. need to be taken up to preserve the vigour and productivity of clumps.

Under the selection system applied to the clump-forming sympodial bamboos, the clump itself forms a small sample in which thinning, improvement cuttings, harvest cuttings and de-congestion activities are conducted to secure even distribution of the culms. Cutting cycles of 2 to 5 years are preferred even though 3-or 4-year cycles seem to be the optimum for obtaining maximum yield. Selective cutting should be conducted with minimum disturbance. It is essential to retain a portion of the old culms (more than one year old) and all of second-year culms for mechanical support of new shoots and to maintain the rhizomes in full vigour.

Elaborate cutting rules are given in many working plans in India to streamline bamboo management and harvesting. Felling rules followed in India prohibit cutting of shoots of the last rains, removal of roots, or cutting culms at more than 30 centimetres from the ground, except where density of the clump makes this impracticable. For a bamboo species like *D. strictus* and a few other species, time when felling is to be carried out, height of culm cutting, number of culms to be cut, cleaning and improvement thinning are also clearly specified. Supervision to assure compliance with the rules also becomes part of the management strategy for bamboo.

Culm Selection System vis-a-vis Selection System

Bamboo felling is usually done through selection of culms in such a way that the production of new culms takes place continually. The term 'culm-selection system' was used for the first time in Ramnagar Working Plan, Uttarakhand and appears to be the most suitable name for the system of bamboo working. This system differs from the well-recognised 'selection system' used for working trees. It involves selection of culms under definite felling rules to ensure harvesting and regeneration, with adoption of tending as part of the system and production of crop of a distinctive character. As in selection system, it envisages felling cycle, exploitable age and regulation of yield.

(b) Clearfelling system:

The disadvantages of selection felling are offset under the clearfelling (or clear-cutting) system. This system offers possibilities with its simplicity and concentration of working, scope for mechanization. However, the disadvantage is the requirement for a longer felling cycle since a clear-felled clump taking longer to mature into a full-sized production system as compared to selection felling. The choice of a system is a matter for decision by forest managers, though experience indicates that selective cutting gives greater yield than clear-cutting and hence preferable. In the case of non-caespitose monopodial bamboos, although clear-felling would be most practical method, it may be desirable to retain a few regularly spaced standing culms per ha, so as to ensure the maximum vigour and productivity of rhizomes.

Bamboos are worked generally on felling (cutting) cycles of 3 or 4 years and of these two, four years is generally adopted in U.P., M.P., Maharashtra, etc. The felling rules vary from state to state. All rules include the following points, which are of basic importance:

4.4 Felling

Bamboo removal in India is very low considering the area and growing stock of bamboo and size of user groups in the country. Low removal is a major factor behind the perpetual shortage of bamboo for artisans and industry, notwithstanding the fact that India has the largest area under bamboo in the world. Non-removal of silviculturally harvestable culms leads to their decay which, in turn, has a cascading effect, ultimately leading to lower growth rate than many other countries. It is, therefore, very important that felling should take place in the bamboo forest as per silvicultural rotation applicable to respective species and sites. This would increase yields and enhance supplies to the industry. This will also help reduce the fire hazard, disease incidence and other related management problems. Therefore, all the bamboo bearing forests, and the private and revenue forests, ought to be covered by working/ management plans, approved by the government. Felling is usually carried out by contractors who have little or no knowledge and interest in sustainable and scientific removal of produce. The plans should, therefore, clearly prescribe bamboo management guidelines, harvestable stocks as well as the number of culms to be retained during harvest. In community-owned areas too, SFDs should develop standards with local communities to ensure sustainable harvest of bamboo. People in and around bamboo forests and other growers can be sensitised and trained on management of bamboo forests and plantations. Local communities should be involved in felling in preference to contractors.

A number of harvest and transit restrictions are in place that do not allow felling of bamboo in different situations; detailed discussion on such aspects is available in the chapter on 'Legal and Policy Issues'. In order to prevent illegal felling, regulation ought to be developed prescribing stricter preventive and punitive measures.

Basic tenets of bamboo felling

(I) Restriction on cutting of one-year and sometimes even two-year old culms,

(ii) retention of some older culms for support of immature ones. In U.P. , the prescription is generally to keep as many old culms as are the new culms subject to minimum of six old culms in each clump but in M.P., the number of minimum number of culms, both new and old, is fixed according to quality class,

(iii) prohibition on removal of rhizomes,

(iv) regulation of the height at which bamboo should be cut. The minimum height at which the bamboo should be cut is generally 15 centimetres with the condition that at least one node should be left.

(v) insistence on cutting with a sharp instrument so that the stump does not split,

(vi) in case of flowering, the bamboo should be cut only when the seed has been shed, and

(vii) the period of working should ideally be November to March.

4.5 Regeneration in Forest Areas

Gregarious flowering results in large-scale availability of bamboo seeds in the forest: a 40 square metre clump of *D. strictus* can produce 160 kg of seeds. Due to availability of large quantities of seed in the wild, a huge build-up of rodent population takes place, which later invades agricultural fields playing havoc with grain production. In the early 1960s and 1970s, a coincidence was observed between large-scale bamboo flowering and severe famines in north-east India. Pre-emptive action plans should be in place for anticipated gregarious flowering, especially the areas with higher bamboo diversity. It is, further suggested that in year of gregarious flowering superior clumps should be identified for retention and collection of seeds and larger population of clumps should be extracted before seed set. The seed of such superior clumps should be used for regeneration of the forest.

Bamboo clumps keep on producing culms through continuous development of rhizomes. New clumps are formed by natural seeding resulting after sporadic flowering. The blanks, if any, are also filled by planting. In case of gregarious flowering, when all the clumps in the area die, regeneration comes up profusely from the seeds provided it is protected from rodents before germination and from cattle grazing after germination. Otherwise artificial regeneration is resorted to. In fully developed clumps, bamboo does not require weeding and cleaning in the same sense as is required by tree species, as it grows very fast and attains its total height by the end of rains. But cleaning and tending of clumps has to be done to facilitate growth of new culms. However, in areas where natural seedlings appear as a result of flowering or gap planting generally three weedings are done in the first year and two in the second year.

4.6 Propagation

Propagation in bamboo is not a simple task as it is affected by many uncertainties. The methods of propagation also vary depending on the type of bamboo species and the response of the bamboo species to a particular method. For most bamboo species, propagation through rhizome ensures the maximum percentage of success. But rhizome multiplication is a cumbersome and time consuming process, especially for mid-sized and large-sized bamboo species. Propagation through culm cuttings, either two noded or three noded culm cuttings is successful for most midsized and small bamboos like *D. stocksii, D. strictus*, etc. Rhizomatous branch cuttings are resorted to when profuse side branches are formed and also when the culm diameter is large and does not fit in the standard vegetative propagation beds like in the case of *D. brandisii, B. balcooa,* etc. In a species like *G. angustifolia*, even single nodal segments or apical shoot cuttings have been fairly successful. A detailed description of various propagation techniques is given in the Quality Plant Production chapter.

General rules for working bamboo crops are:

(a) immature culms less than one year old are not to be cut,

(b) in a clump containing 12 culms or more, at least six mature culms over one year old should be retained,

(c) culms should not be cut below the second node; in any case not higher than 30 cm above ground level,

(d) no felling to be done during the growing season, viz., July to September in North India, and

(e) no cutting to be done in the year of flowering; flowered clumps to be clear felled after they have shed their seeds.

4.7 Establishment of New Plantations

This section deals with plantation of bamboo in forest areas and wastelands. Specific techniques for plantation in agricultural land are described in Agroforestry chapter.

4.7.1 Choice of species

Nineteen species have been identified by National Mission on Bamboo Application (NMBA) and National Bamboo Mission (NBM) as industrially important species suited for commercial cultivation based on market preference, superior physical and mechanical properties, widespread distribution and availability. *D. latiflorus* has been included in the list of recommended plantation species in Table 4.2, by NBM recently (http://nbm.nic.in/WorkingGroup3.doc).

Table 4.2: List of 19 industrially important bamboo species identified by NMBA

S. No.	Species	S. No.	Species	S. No.	Species
1.	*Bambusa bambos*	8.	*Dendrocalamus brandisii*	15.	*Melocanna baccifera*
2.	*Bambusa nutans*	9.	*Dendrocalamus giganteus*	16.	*Ochlandra travancorica*
3.	*Bambusa pallida*	10.	*Dendrocalamus hamiltonii*	17.	*Schizostachym dullooa*
4.	*Bambusa polymorpha*	11.	*Dendrocalamus stocksii*	18.	*Phyllostachys bambusoides*
5	*Bambusa tulda*	12.	*Dendrocalamus strictus*	19.	*Dendrocalamus latiflorus*
6.	*Bambusa vulgaris*	13.	*Dendrocalamus asper* (exotic)		
7.	*Bambusa balcooa*	14.	*Guadua angustifolia*		

As the choice of species varies with site and end-use, appropriate species of bamboo need to be prioritised on the basis of growth rate, adaptability, use, demand and supply for undertaking large-scale plantations for future industrial and other needs.

4.7.2 Site selection

The site selected in the forest should be cleared of weeds and other undesirable vegetation, though some trees, if existing already, may be left standing to provide protection and shade. The land should be ploughed thoroughly and needs to be done well in advance. Soil amendments like biochar, flyash, compost or farm yard manure may also be beneficial to improve soil nutrition and quality. Fencing is also recommended using low-cost barbed wire strung across angle iron poles for boundary demarcation and to prevent stray grazing. Cattle proof trenches (CPTs) or elephant proof trenches (EPTs) may be dug as per requirement.

4.7.3 Planting and establishment

In bamboo plantation establishment, the quality and height of the planting material should be atleast one metre with sufficient number of tillers to survive grazing by wild animals, rabbits etc. The planting material should be placed in pits at the plantation site as early as possible. Ploughing is not required if pits are used. The planting material should be stored in shade at a cool location and watered regularly. The spacing to be followed will depend on the type of species, the objective of the plantation, local climate and site conditions. Closer spacing of 4m x 4m or less may be appropriate for small sized bamboo species like *T. oliveri, D. stocksii* and *D. strictus*, while for medium to large sized species like *B. balcooa, D. asper, B. nutans* and *B. tulda* 5m x 5m size should be appropriate. For large-sized species like *D. brandisii* and *D. giganteus* a spacing of 7m x 7m may be more appropriate.

If the objective of the plantation is for soil conservation along eroded slopes or river bank stabilization, the spacing may be reduced to 3m x 3m even for mid-sized bamboo species. The pit size nevertheless for all bamboo species should ideally be less than one cubic metre There are different methods of planting like bund and trench method, triangular spacing method, pit method or planting in trenches dug upto one metre. Any of the methods may be adopted depending on the terrain, type of species, purpose of the plantation, availability of labour and economic considerations.

4.7.4 Irrigation and fertilizer application

It is well known that bamboo thrives in conditions of adequate moisture and soil depth. Providing irrigation is mandatory in commercial plantation and is an important input which enhances the health and productivity of the clumps. Irrigation requirement varies with micro-climate and other edaphic conditions. In the initial stages of plantation establishment, irrigation is an essential input. Different methods of irrigation have been followed by farmers traditionally like channel irrigation, earthen pot and wick method and drip irrigation depending on water availability and economic resources of the farmer. For commercial bamboo plantations especially in semi-arid and sub-humid zones, provision for drip irrigation should be planned.

Application of fertilizers is also an important management practice followed in intensively managed plantations. Bamboo responds well to fertilizer application. Under normal soil conditions the composition of NPK should be in the ratio of 5:2:1 or 4: 2:1 (NMBA, 2004). Fertlizer application should be done in the first year of planting and the chemical fertilizers should be placed in planting pits and mixed well with soil before planting of bamboo planting stock and two months after planting in two split doses. A general norm in bamboo fertilizer dosage is 150g N + 150g P + 150g K per plant (NMBA, 2004). In the second application, the fertilizers should be placed in small trenches round the clump when the soil is sufficiently wet and then covered with soil. It is also possible to cultivate bamboo in organic way without chemical fertilization especially through in-situ vermicomposting between the bamboo rows and by utilizing the copious litterfall in bamboo.

4.7.5 Clump management and harvesting

In the first year of establishment a red colour band is done, in second year a yellow colour band, in the third year a blue band and fourth year a black colour band is recommended and the cycle may be repeated every 5 years (Fig. 4.3 and 4.4), (NMBA, 2004). Regular clump management may ensure higher productivity besides minimizing wastage. Loosening the soil around the clumps at least twice a year around one meter away from the clump can improve soil moisture and ensure good rhizome development. Annual clump cleaning or tending is an important activity to prevent congestion and also improve aeration and easy extraction of culms when required. Maturity marking is also an important activity for scientific harvesting of mature culms. The age of the culm is an important determinant of its physical, mechanical and chemical properties, which is important for its utilization value. One way is to have single-band colour system.

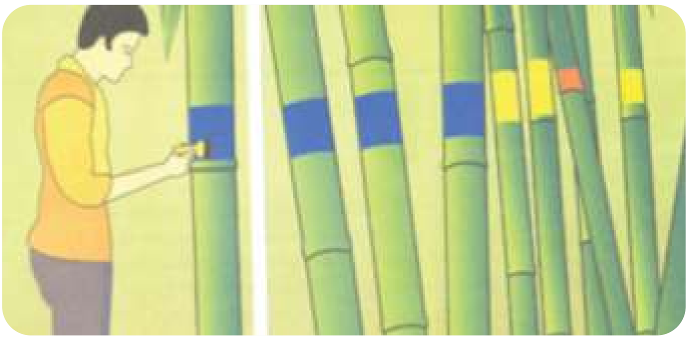


Fig. 4.3: Maturity marking of culms using different colour codes. The same colour band denotes culms that have come up in that particular year only

Fig. 4.4: Maturity marking done for *G. angustifolia*. The red band indicates culms which have come up in first year after planting and blue band shows the culms that have come up in third year after planting

A bamboo clump may get congested if it is not worked for several years. For species like *D. strictus, B. bambos, B. balcooa* which are sympodial and tend to have closely spaced culms, this problem is severe. For a species like *B. bambos* which has thorny side branches, this problem is more acute and in such cases it may be necessary to resort to the 'tunnel system' or 'horse-shoe system' of extraction or harvesting of culms (Fig. 4.5).

Tunnel system: In the tunnel system of harvesting, two tunnels are created through the centre of the clump effectively dividing it into four sections. The tunnels provide access to the inside of the clump and allow easy working of the clump.

Horse-shoe system: In the horse-shoe system of harvesting, the clump is worked in a horse-shoe pattern or an inverted V shape by making an opening opposite the area of maximum density of the culms (NMBA, 2004).

The ideal clump structure for commercial plantations raised primarily for extraction of the culms should be in the ratio of 3:3:3:1 for the first, second, third and fourth year, respectively. Whereas in a bamboo plantation raised exclusively for shoot production, the clump structure should ideally be in the ratio of 4:4:2 for the first, second and third year respectively. As a thumb rule in commercial plantations for culm extraction, the number of harvested mature culms should not normally exceed the number of healthy shoots that emerged and grew into full-sized culms the previous year. In culm-cum-shoot plantations, the thumb rule is that not more than 30 per cent of shoots should be harvested. In exclusive shoot plantations, up to 50-60 per cent of the new emerging shoots may be harvested annually.

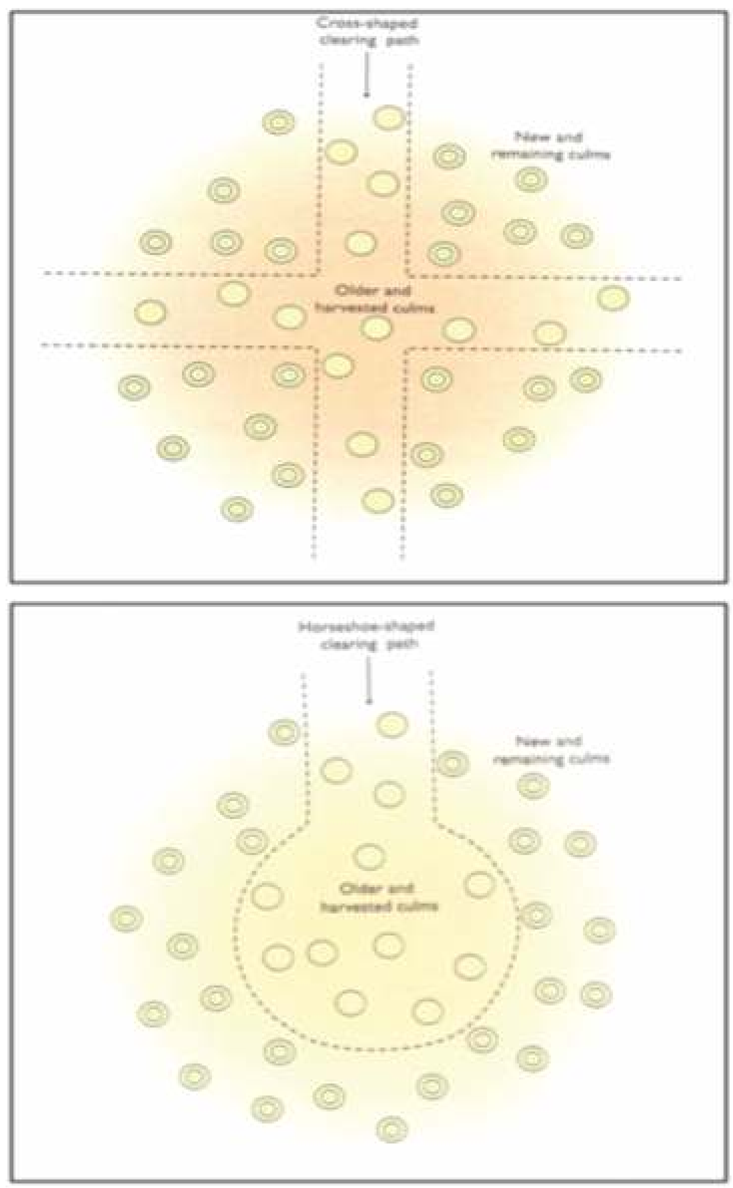


Fig. 4.5: (a) Tunnel system (b) horse-shoe harvesting system

As managing bamboo requires technical knowledge, SFDs should act as facilitators to forest-dwellers and render help to them in better management of bamboo in community forests and plantations. SFDs can entrust van panchayats, joint forest management committees, self-help groups, bamboo growers' cooperative societies, etc. in protecting and managing the extensive bamboo forests. Share can be given to such agencies from the sale proceeds.

4.7.6 Stacking and storage of harvested culms

Ideally extraction of culms should be done during the dry season. Traditional knowledge suggests that the extraction should be done on new moon days when sapflow is likely to be the lowest which will also result in the culm being less prone to insect/pest damage. After harvesting of bamboo culms, it needs to be properly stacked and stored for a certain period of time for seasoning and to bargain for a better price in market. Immediately after harvesting and throughout the storage period, the culms should be stacked vertically (Fig. 4.6) Horizontal stacking should be avoided as far as possible as it puts pressure on culms at the bottom of the pile and may cause injury or deformity of the lower culms. Vertical stacking also facilitates uniform and quicker drying since a larger surface area of the culm is exposed. When stacked, the stacked area should have a concrete or cement flooring, if not, at least a tarpaulin sheet or polythene should be spread at the bottom to reduce vulnerability to termites and borer pests.

Fig. 4.6: Harvesting and stocking of culms of *D. stocksii* in Konkan region of Maharashtra

4.8 Post-Plantation Activities (Year-1 to 5)

4.8.1 Year-1 (establishment year)

Before planting the bamboo in the designated pit at the onset of monsoon, an initial application of fertilizer and FYM @10 kg per pit may be done and the second dose of chemical fertilizer 2-3 months after planting is recommended. In the first year, special provision for irrigation should be made during summer so that the plants do not suffer from moisture stress during early establishment and growth phase. Regular weeding is to be done in the first year so that the plants are not smothered by weeds. After the monsoon, soil loosening, mulching and mounding may also be done. Fencing should also be ensured.

4.8.2 Year-2 (plantation nursing)

The pattern of activities outlined in the first year continues in the second year. Casualty replacement is also done. Irrigation, soil loosening, soil mulching and mounding are repeated. Gaps in fencing, if any, need to be attended. Maturity marking may also be initiated.

4.8.3 Year-3 (nurturing plantations)

In the third year, the shoots will be considerably taller and more in diameter than the previous year and the clump structure will be apparent. The basic set of activities will be the same as in the preceding year. During monsoon, when the shoots start emerging, the weak and diseased shoots may need to be removed or discarded. Weeding requirements will be less as compared to previous year.

4.8.4 Year-4 and 5 (plantation maturity)

By the fourth year and fifth year the plantation will be in the full phase of establishment, the canopy and clump structure would be stabilized and healthy and more vigorously growing clumps will be visible. The core activities of previous years will continue.

Maturity marking and tending of culms and clumps attain precedence (Figs. 4.7 and 4.8). The leaf litter can be used for in-situ vermicomposting to reduce input costs and enhance productivity of the clumps. Weeding requirements will be considerably reduced due to thick litter cover on ground and canopy coverage.

Fig. 4.7: Mature commercial plantation of *Dendrocalamus stocksii* in Belgavi, Karnataka

Fig. 4.8: Commercial plantation of *D. asper* near Bengaluru

4.9 Rehabilitation of degraded bamboo

Improper management and care of bamboo in the forest results in damage to regenerating shoots, congestion within clump, twisting of culms, poor quality of produce, loss of opportunity of economic yield, deterioration and decay of culms and degradation of the clump. Degrading bamboo clumps can be revived with suitable silvicultural interventions.

Rehabilitation of degraded bamboo forests in Madhya Pradesh: A case study

Under the UNDP sponsored project 'Integrated Land and Ecosystem Management to Combat Land Degradation and Deforestation' implemented by Madhya Pradesh Forest Department, an area of 15,000 ha degraded bamboo forest was taken up during 2010 for treatment in five districts viz. Betul, Chhindwara, Umaria, Sidhi and Singrauli. Poor families were allotted 20 ha area each for treatment of degraded bamboo clumps in four years (5 ha per year). Monthly remuneration of Rs. 2,500 per family (amounting to Rs. 30,000 per year) was deposited in their bank accounts in lieu of work of participatory co-management rehabilitation which included weeding, cleaning of congested clumps, soil work, protection, etc. This helped the bamboo forest revive the areas. The beneficiaries also earned about Rs. 2000 from sale of 500 discarded bamboo culms. The remuneration was reduced to Rs. 5,000 per year during 5th to 7th year as money poured in from the sale of bamboo culms. It is estimated that clumps would improve from 15-20 culms to 25-35 culms. From 5th year the harvest of bamboo is expected to be 1200 culms per ha (i.e. 120 clumps per ha x 10 culms per clump). From an area of 5 ha, a revenue of Rs. 60,000 is expected. Revenue is expected to rise further as number of culms increase gradually (12-15 culms per clump per year). Additional Rs. 15,000 per ha per year would also be accrued from sale of foliage and other biomass to the tune of 5 tonne per ha per year.

Table 4.3: Rehabilitation of degraded bamboo forests in Madhya Pradesh

Year	1	2	3	4	5	6	7
Input (Rs.) Wages@ Rs. 2500 per month	30,000	30,000	30,000	30,000	5,000	5,000	5,000
Revenue (Rs.)							
Discarded bamboo	2,000	2,000	2,000	2,000	-	-	-
Sale of bamboo clumps	-	-	-	-	60,000	65,000	70,000
Bamboo biomass	-	-	-	-	15,000	15,000	15,000
Total Revenue (Rs.)	2,000	2,000	2,000	2,000	75,000	80,000	85,000
Earnings/Benefits	-28,000	-28,000	-28,000	-28,000	+70,000	+75,000	+80,000
Accumulated Earning/Loss	-28,000	-56,000	-84,000	-1,12,000	-42,000	+33,000	+1,13,000

Economic analysis based on 7 years at 12 per cent discount rate showed net present value (NPV) of Rs. 29,820, benefit:cost ratio of 1.28:1 and internal rate of return (IRR) of 21.4 per cent, implying that the intervention was financially viable. This also contributed to employment generation and poverty alleviation among the poor tribals (ICFRE, 2014).

4.10 Research and Development

4.10.1 Appropriate spacing in bamboo plantations

Closer spacing of 4m x 4m or less may be appropriate for small sized bamboo species like *T. oliveri, D. stocksii, D. strictus*, while for medium to large sized species like *B. balcooa, D. asper, B. nutans, B. tulda* 5m x 5m size should be appropriate. For large-sized species like *D. brandisii, D. giganteus* a spacing of 7m x 7m may be more appropriate.

4.10.2 Sustainable harvesting of mature culms

Maturity marking is also an important activity for scientific harvesting of mature culms. Immature culms less than one year old must not to be cut. In a clump containing 12 culms or more, at least six culms over one year age should be retained. Culms should not be cut higher than 30 cm above ground level. Felling should not be done during the growing season; in the year of flowering the flowered clumps should be clear-felled after seed shedding.

4.10.3 Ideal clump structure in bamboo plantations

The ideal clump structure for commercial plantations raised primarily for extraction of the culms should be in the ratio of 3:3:3:1 for the first, second third and fourth year respectively. However, in a bamboo plantation raised exclusively for shoot production, the clump structure should be ideally in the ratio of 4:4:2 for the first, second and third year respectively. As a thumb rule in commercial plantations for culm extraction, the number of harvested mature culms should not normally exceed the number of healthy shoots that emerged and grew into full-sized culms the previous year. In culm-cum-shoot plantations, the thumb rule is that not more than 30 per cent of shoots should be harvested in a given year.

4.10.4 Extraction, stacking and storage of mature culms

Extraction of mature culms should be done during the dry season, i.e., from January to May. The extraction should preferably be done on new moon days when sap flow is likely to be the lowest thereby resulting in lower susceptibility of the culm to insect/pest damage. Harvested culms should be stacked vertically and should not be allowed to come in direct contact with soil.

4.11 Future Strategies

4.11.1 Enhancing productivity

There can be two approaches of increasing productivity of bamboo forests and plantations: Silvicultural interventions and genetic interventions. Silvicultural interventions provide quick results. Fortunately, a lot of knowledge base is available to prescribe appropriate silvicultural measures in different situations. Protocols for raising, managing and harvesting bamboo from forests and plantations, which are already standardized, should be implemented and new protocols can be developed through concurrent research. Assisted natural regeneration and enrichment planting with nursery-grown quality seedlings ought to be undertaken to augment the bamboo resources in the pure and mixed bamboo forest areas. Degraded forest areas should also be planted with suitable bamboo species, wherever possible depending upon ecology, suitability, socio-economic relevance and commercial feasibility

4.11.2 Expanding area

Productivity enhancement aims at increasing production per unit area. Another way of increasing availability of bamboo can be by expanding area of bamboo forests and plantations. There is hardly any scope of increasing area under forests, however, planting of bamboo outside the forest has much scope. Large scale plantations of bamboo should be promoted in private lands, community lands and wastelands. State Governments should consider leasing out the non-forest government /revenue/ lands, presently devoid of tree cover, to panchayats, communities, bamboo-based industries, or forest corporations for raising bamboo plantations. Other departments concerned with roads, railways, rivers, canals, etc. can be mobilised to plant bamboo as linear or strip plantations. This can be done by those departments themselves or with the help of local people by providing incentives. Technical assistance can be provided by SFDs directly by themselves or, if needed, by involving research organisations. Forest land can be leased to industry on long-term agreement to undertake planting of bamboo.

Large bamboo nurseries of priority species should be established in the bamboo growing areas by the SFDs, forestry research organizations, industries, NGOs, communities and individuals, to ensure production of quality planting stock.

4.11.3 Sustainable management

Grazing must be effectively controlled/ regulated in bamboo areas, especially during times of bamboo regeneration and new culm emergence. SFDs ought develop standards to ensure sustainable harvest of bamboo; local communities may be roped in this process for regulating harvest in community-owned bamboo areas. In year of gregarious flowering, superior clumps should be identified for retention and collection of seeds and larger population of clumps should be extracted before seed set. The seed of such superior clumps should be used for regeneration of the forest. The possibility of bamboo flowering prediction model should be explored and preparation of large scale propagation plans should be developed with long-term view. Intensive and participatory approach to protection and management must be done adopted for bamboo forests with active participation of local communities to reduce theft of bamboo culms and prevent unscientific culm removal by contractors. In bamboo native areas regulation ought to be developed prescribing stricter preventive and punitive measures against over-exploitation and smuggling from forests under the guise of plantation-grown bamboo. A network of bamboo growers may be created to allow exchange of information and facilitate collective action. A monthly bulletin or magazine may be of great help to the growers. Training programme for communities and individuals must be conducted covering raising of nursery stock, planting and management of bamboo forests and plantations. Grazing must be effectively controlled/ regulated in bamboo areas, especially during times of bamboo regeneration and new culm emergence. Intensive and participatory approach to protection and management must be done for bamboo forests with active participation of local communities to reduce theft of bamboo culms and prevent unscientific culm removal by contractors.

CHAPTER - 5

QUALITY PLANT PRODUCTION

5.1 Introduction

The productivity of bamboo depends upon edapho-climatic factors, species, stocking intensity the biotic interference. The average productivity of bamboo in India is very low in comparison with China (Gupta, 2008). However, industrially important bamboo species like *Bambusa balcooa, Guadua angustifolia, Dendrocalamus brandisii, D. stocksii* in plantations can be expected to give productivity in excess of 25 tonnes per ha per year (Rane *et al.,* 2016; ICFRE, 2016). Species like *D. giganteus, D. asper, B.balcooa*, etc. may attain maximum 20m height in the first year of growth. A shortage of bamboo supply exists in most of the countries, and the gap between supply and demand will further widen in the future (INBAR, 1995). To meet the ever-increasing demands, large scale plantations with traditional high-yielding species and clones need to be raised. There is also need to improve the productivity of bamboo plantations across the country (Tomar *et al.*, 2009). The unavailability of genuine, quality planting stock of bamboo species is a major constant for large-scale plantations (INBAR, 1995). Clonal identification, selection of genetically superior clones and there mass propagation for making available to growers is also required (Tomar *et al.,* 2009).

So far, no systematic selection procedure has been employed to improve the planting stock of bamboos for afforestation and reforestation programe in the country. Varietal selection is barely being considered. Very little information is available on the selection of candidate clumps of a bamboo species. Some initiatives were taken in the past for selection of plus clumps of important bamboo species, *viz., B. balcooa, B. nutans, B. pallida, B. tulda, D. giganteus* and *D. hamiltonii.* The selection of plus bamboos have shown superiority over other bamboos (Beniwal and Singh, 1988) and strengthened the understanding of selection of superior clumps for productivity improvement based on phenotypic characters (number of culms per clump, clump height, culm diameter and wall thickness of culms, length of internode, fibre length, straightness and resistance to diseases and pests) from the adult wild populations and plantations.

5.2 Improvement Strategy

Bamboos are the vast genetic resource of the country and have a great potential of producing higher biomass for the benefit of the society. To meet the indigenous demand, bamboo is extracted mainly from the forests and the resource is depleting gradually. Plantations outside the forest are viable alternatives to meet the growing demand. However, there is severe scarcity of planting material of bamboos selected for higher productivity for large scale plantation programme. The vast genetic diversity of bamboo in the country provides ample scope for selection of superior genotypes for improved productivity, quality of product, development of bioresource and sustainable utilization.

Conventional genetic improvement strategies are largely not feasible in bamboos due to long and unpredictable flowering cycles (Banik, 1995 & 1996). Hence, selected clones, evaluated through field trials are generally considered as superior stock (Banik, 1995). However, the purpose of an evaluation trial is to identify individuals of desirable genotypes. Since all of the characters of interest in bamboo, irrespective of end-use, are quantitative and controlled by many genes, this objective can be realised only when it is possible to separate the effects of the environment, in which clones have been raised, from genetic differences between them (INBAR, 1995). In turn, this can only be done when the material has been randomized over the area occupied in the trial and also across different locations in form of multi-location trials (INBAR, 1995). Hence, search for promising bamboo genotypes is an important step in bamboo genetic improvement programmes. For deployment of the productive genotypes in the field, a large-scale clonal propagation technique is also required. The strategy involves selection from an unimproved base population for best provenances/populations, selection of candidate plus clumps and their further evaluation for identification of plus clumps and establishment of rhizome banks with the selected plus clumps and their mass multiplication for establishment of multilocation clonal trials for clonal selection.

During the ICFRE World Bank Forest Research, Extension and Education (FREE) Project between 1995 and 2000 and in many other externally funded projects, the following initiatives were taken on prioritized bamboo species, *viz., B. bambos, M. baccifera, B. balcooa, B. tulda, B. nutans, O. travancorica, D. strictus, P. stocksii, D. hamiltonii,* etc:

- Survey of natural forests and plantations and selection of candidate plus clump (CPC),
- Collection of reproductive material,
- Developing suitable technique for mass multiplication and production of superior quality planting stock, and
- Ex-situ conservation and evaluation of gene resources.

These efforts have led to establishment of species-cum-provenance trials, collection of promising CPCs, and establishment of CPC evaluation trials in the field spanning across various institutes of ICFRE, agricultural universities, State Forest Departments, etc.

5.2.1 Parameters of selection and evaluation

The selection of plus bamboos have shown superiority over other clumps (Beniwal and Singh, 1988; Kochhar *et al.*, 1990). Investigations on the clump characteristics (clump height, clump circumference, culm number, culm girth and culm thickness) in populations of *B. tulda, D. hamiltonii* and *B. pallida*, have concluded that phenotypic culm parameters are least affected by environment in comparison to clump morphology. Thus, culm diameter alone or culm height can be used as a selection criterion. Hence, superior clumps based on phenotypic characters (number of culms per clump, height, diameter and wall thickness of culms, length of internode, and resistance to diseases and pests) can be selected from wild populations and plantations (Banik, 1996). Most of the selections in past are based on the following important characters (Table 5.1):

Table 5.1: Parameters for selection and evaluation

S.No.	Qualitative criteria	Quantitative criteria
1.	Straightness	Height of culms
2.	Excessive branchiness	Girth/diameter of culms
3.	Thorniness	Internode length (at 5th internode)
4.	Disease /pest susceptibility or resistance	Wall thickness (at 5th internode)
5.	Flowering/seeding behaviour	Clump diameter/girth

5.2.2 Improvement initiatives

The history of genetic improvement of bamboos is recent and started only about 30 years ago in Japan and China, and more recently in the Indian subcontinent (Banik, 1996). In the short-term strategy, the major activities regarding breeding may rely on and consist of the following:

Step-I: Exploration of diversity, identification of ideal species, and mapping their natural range and description of phenotypic variations throughout the range.

Step-II: Selection of species/provenances/individuals having desired qualities.

Step-III: Mass propagation of desired individuals for reforestation purposes.

Step-IV: Conservation and maintenance of germplasm for further use.

These steps can go simultaneously; steps-II and -III can bring immediate gain in improvement (Banik, 1996). It has been established that mere selection of best phenotypes can give 5 to 20 per cent genetic gains (Viana *et al.*, 2009). This gain when calculated in terms of production of biomass per ha per year, can give sufficient revenue returns.

Research work on collection and evaluation of genetic resources of bamboos started in India in 1970s when a provenance trial on *D. strictus* was done at FRI, Dehradun. This was followed by the work on selection, evaluation and ex-situ conservation of several economically important bamboos of north-eastern region in State Forest Research Institute, Itanagar. Later ICFRE took initiatives in identification, evaluation and conservation of the economically important species of bamboos. Accordingly, natural forests and plantations of *D. strictus, B. bambos, B. balcooa, B. tulda, B. nutans, D. hamiltonii, M. baccifera, O. travancorica* and *P. stocksii* have been surveyed throughout the country and superior genetic resources collected and multiplied in limited manner.

Under the World Bank FREE project, efforts were made by ICFRE, in collaboration with several research organizations, to identify and collect promising genetic resources of the important bamboo species and a common action plan was prepared for selection of plus clumps and development of criteria for selection and evaluation of selected germplasm in the form of evaluation trials. This exercise resulted in identification and establishment of valuable germplasm of some selected economically important bamboo species across the country.

In north-east India, the systematic conservation and improvement first started at Van Vigyan Kendra (VVK), Chessa under State Forest Research Institute (SFRI), Itanagar in eighties. SFRI and RFRI, Jorhat are pioneers in bamboo improvement programme through selection of candidate plus clumps of important species like *B. balcooa, B. nutans, B. pallida, B. tulda* and *D. hamiltonii.* VVK, Chessa carried out selection of promising genotypes from different areas of Arunachal Pradesh from 1981 to 1983 and selected 120 promising clumps of 6 important bamboo species, *viz., B. bambos, B. balcooa, B. nutans, B. pallida, B. tulda, D. hamiltonii* and *D. giganteus* and established them at Chessa and Namsai (Beniwal and Singh, 1988). Presently, only limited number of representative clones is surviving at Chessa. During the same period, 35 different species of bamboos were also established in Chessa bambusetum (Beniwal and Haridasan, 1988).

Rain Forest Research Institute (RFRI) has been working in the area of bamboo research since 1990. RFRI carried out intensive survey during 1998-1999 to select superior clone (genotypes) from Assam and parts of Meghalaya. Around 1355 clumps of six commercially important species, *viz., B. bambos, B. balcooa, B. tulda, B. nutans, B. pallida* and *D. hamiltonii* were evaluated for growth performance in homestead garden and forest areas and 249 promising clumps were selected and established in germplasm bank. However, some of them could not survive and again in 2008-2009 another attempt was made and 93 CPCs were collected and established in the germplasm bank. Recently, attempts have been made to evaluate the germplasm and identify promising clumps of *B. tulda, B. nutans* and *D. hamiltonii.*

Under ICFRE World Bank (FREE) project, Sirsi Forestry College, Sirsi has selected CPC of *B. bambos, D. strictus* and *P. stocksii*. Similarly, TNAU, Coimbatore has selected CPCs of *B. bambos* and *D. strictus*. They have established germplasm bank of CPC material of these spies in Sirsi, Karnataka and Mettupalayam, Tamil Nadu. The FRI, TFRI and IWST, have also established germplasm bank of economically important species of bamboo under their jurisdiction. This germplasm bank also consists of some CPCs of industrially important bamboo species. A germplasm collection of reed bamboo (Ochlandra spp.) has been established in KFRI, Velupadom under a CSIR NMITLI project. The accessions have also been characterized for their physico-chemical properties. Low lignin/high cellulose and low silica accessions, which shows promise for the paper industry have been identified and are currently being field tested.

There was a lack of continuity in bamboo improvement programs for a decade thereafter and further evaluation, multiplication and dissemination of the selected germplasm in different agroclimatic conditions was affected. Evaluation trials established with superior clumps are valuable resource for further selection and propagation of the best performing genotypes. The selected germplasm exists in the field condition under the evaluation trials for a considerable time period since their selection and establishment. During 2014-2016, with the financial support of NBM, initiatives were taken by ICFRE through FRI, Dehradun to revisit the ongoing bamboo evaluation trials/plots established by ICFRE institutes/other institutes in past across the country and identify the promising ones from the germplasm banks, evaluation trials and demonstration plots. This project was executed across the country by five ICFRE institutes, *viz.*, FRI, TFRI, IWST, Bengaluru, IFP, Ranchi and RFRI, Jorhat on priority species, *viz., D. strictus, B. bambos, B. vulgaris, B. tulda, B. nutans, B. balcooa, D. hamiltonii, D. stocksii, D. brandisii* and *D. somdevai*.

In the first phase, the ongoing bamboo evaluation trials/plots established by ICFRE institutes/other institutes with the selected clumps of bamboo species in different regions across the country were revisited and evaluated with a set of selection parameters. Promising superior clumps were identified through multi-trait evaluation. The rhizomes/offsets of the superior clumps were collected for further multiplication and for establishment of rhizome banks. This activity has resulted in identification of 289 superior clumps of ten selected bamboo species across five ICFRE institutes. The summary of the selected clumps is presented in the Annexure II.

The selected clumps have revealed higher selection differential for culm height, internode diameter, internode length and number of culms per clump which indicate their potential for achieving higher genetic gains once they are deployed in the field after multiplication in successive generations. Hence, the selected material is promising and need to be mass propagated for its dissemination to the plantation programmes.

5.3 Species-wise Availability of Superior Clumps

a. *Dendrocalamus strictus*

It is one of the most widespread bamboos in the Indo-Malaysian zone. *D. strictus* growing in drier part of western India is known to have solid culms (Kadambi, 1949), and in other parts the culms are hollow with thick walls. Culms vary in size, according to climate: 6-15 m high and 2.5-7.5 cm in diameter (Prasad, 1948). The internodes are 30-45 cm long and thick-walled. Three growth forms of clumps can be recognized in India (Banik, 1996). The species is extensively used as raw material in paper mills and also for a variety of purposes such as light construction, furniture, musical instruments, bamboo board, mats, sticks, agricultural implements, rafts, baskets, woven wares and household utensils. Young shoots are edible and used as food. Leaves are used as fodder.

Fig. 5.1. Selected clumps of *Dendrocalamus strictus* at FRI

During 2006-2009, a germplasm bank of *D. strictus* was established in 2008 at FRI campus, Dehradun. This germplasm bank consists of selected 750 clumps collected from 16 different states from the range of distribution of this species. After six years of growth evaluation at a single site 24 promising clumps Annexure II, were identified by FRI based on multi-trait evaluation for further multiplication (Fig. 5.1). A considerable improvement (based on selection differential) is expected with the use of the selected 24 clumps. The selection differential for culm height, internode diameter, internode length and number of culms per clump indicate a potential for achieving higher genetic gains by deployment of the selected germplasm after multiplication in successive generations.

B. *Dendrocalamus somdevai*

D. somdevai also called as 'magar', distributed in lower hills of Himachal Pradesh and Uttarakhand in an altitude range between 600 m – 1000 m (Naithani, 1993; Naithani and Pal, 2001). It is differentiated from D. hamiltonii on the basis of ligule (dentate), anther tips (apiculate) and stigma (solitary and glabrous). It is a thick walled bamboo (2.5 to 3.5 cm at 5th internodes) with very small lumen and sometimes no lumen at base. This is an excellent green fodder and available during winter in the hills. Being a huge, robust and vigorous clump forming bamboo, it is a multipurpose species widely used for scaffolding, house building, fencing, making ceilings and also in the development of farm-oriented cottage industry in village.

Fig. 5.2: Selected clumps of *Dendrocalamus somdevai*

Survey and selection work of superior clumps was carried out by FRI in year 2015 from Himachal Pradesh and Uttarakhand and candidate plus clumps were selected (Fig. 5.2). Candidate plus clumps and comparison clumps were assessed by Index Selection method. Based on surveys, following seven promising clumps have been selected Annexure III The selection differential for these traits and indicate that gains can be achieved from selected germplasm.

c. *Bambusa bambos*

B. bambos also known as 'Indian thorny bamboo' is a species of tropical dense clumping bamboo native to Southeast Asia. It is has great commercial and utility value to mankind and wildlife. It attains the best growth in moist deciduous forests up to an altitude of 1000 metres. It is found almost throughout India, and is common in central and south India. It is generally not cultivated due to difficulty in managing thorny side branches. The fast growing, strong woody culms of *B. bambos* have an average diameter between 10-18 cm, and are between 20-30 m tall The internodes are dark green coloured with very thick walls. Culms are used for house construction, scaffolding, rafters, thatching and roofing, handicrafts and art objects, basket making, bows and arrows, furniture, floating timber and rafting, cooking utensils and fencing. The raw material of this bamboo is also an important source for paper pulp and panel products. Shoots and seeds are edible and leaves are used as fodder and medicine.

The germplasm of the selected superior clumps of *B. bamboos* is available with IWST, Bengaluru and TFRI, Jabalpur. A list of promising clumps of *B. bambos* along with the passport data has been presented in Annexure IV.

D. *Dendrocalamus stocksii* (syn. *P. stocksii*)

D. stocksii (syn. *Oxytenanthera stocksii/Pseudoxytenanthera stocksii*) is naturally distributed in central Western Ghats. *D. stocks*ii has medium-sized, stout solid and strong culms. Though the natural distribution of this species is in humid tropics with lateritic soil type, this species has a wide adaptability and comes up well in tropical humid, sub-humid and semi-arid conditions under black and red soils as well. It is the most preferred species after *B. bambos and D. strictus* by the farmers in Peninsular India. *D. stocksii* is considered as an important agroforestry species, ideal for plantations in watershed and coastal regions. It is planted as a component of home-gardens or as pure blocks plantations (Viswanath *et al.*, 2013).

This species is endemic to central Western Ghats and is found in Karnataka, Goa, Kerala and Maharashtra. Its natural distribution is mostly confined to the banks of streams as it requires well drained deep soil. *D. stocksii* is cultivated Konkan belt (Sindhudurg, Ratnagiri, Raigad, Mumbai in Maharashtra, Uttara Kannada, Udupi, Dakshin Kannada in Karnataka and North Goa and South Goa) and is primarily planted around the areca nut gardens and paddy fields. Comprehensive collection of CPC's of *D. stocksii* from central Western Ghats conducted during 2012-2014 under Karnataka forest department funded external project and evaluated under NBM project. A survey was conducted to understand the distribution and ascertain morphological variations in *D. stocksii* along the entire area of its natural distribution in the central Western Ghats of India from Kasargod in Kerala to Ratnagiri in Maharashtra (Fig. 5.3). *D. stocksii* clumps identified were randomly marked for sampling and evaluation, maintaining distance of at least 10 km between two clumps. A total of 100 clumps were evaluated covering a span of 1200 km from Ratnagiri, Maharashtra to Kasargod, Kerala. A list of 66 promising clumps is presented in Annexure V Further variations in accessions in farmers fields have been identified in a NABM funded project implemented by KFRI for the State Bamboo Mission in Maharashtra on "Inventory, identification and conservation of Bamboos of Maharashtra" during 2015-2017

55 mm

43 mm

30 mm

Fig. 5.3: Selection of superior clumps *Dendrocalamus* stocksii on diameter basis in central Western Ghats

The genetic analysis of culm parameters indicate that important traits like culm basal diameter, culm solidness, diameter and length of 5th internode appeared to be heritable traits which has implications for genetic improvement of the species. The tremendous variation observed in various culm and clump characters (Fig. 5.4) during the survey reveal a broad base that can be captured for further improvement and conservation programme (Fig. 5.5). The main stakeholder of this species is the furniture industry which mainly uses this species as a substitute for cane for making high-end innovative furniture. The market potential of this species can be increased further for the furniture industry if *D. stocksii* clumps with average culm diameter in excess of 40mm and a culm wall thickness to culm diameter ratio of 1:3 can be identified and propagated. This dimension of culms may help in better joinery and minimize cracking during its treatment and utilization.

CPC No. 63

CPC No. 65 (Karekundi)

CPC No. 50 (Addukam)

CPC No. 64 (Madavale)

CPC No.88 (Phopali)

CPC No.86 (Dikshi)

Fig. 5.4: Morphological variation in clump parameters in some selected genotypes of *D. stocksii* in central Western Ghats.

Fig. 5.5: Selection and marking of mother plants, seed collection and nursery from selected seeds for genetic conservation and improvement programme of *M. baccifera*.

e. *Bambusa tulda*

B. tulda or Indian timber bamboo is considered to be one of the most useful of bamboo species. It is a tall, sturdy and quick growing bamboo suitable for the production of high quality paper and furniture. It forms a good raw material for various handicraft works, house building, paper industries, fencing and several other useful equipment for day to day life. Because of its strength and durability it is of great demand in the market. Because of its high value, selection of superior clumps of this bamboo was carried out by TFRI, Jabalpur, RFRI, Jorhat and IFP, Ranchi. The list of promising clumps of *B. tulda* along with the passport data, available at different ICFRE institutes has been depicted in Annexure VI.

F. *Bambusa balcooa*

B. balcooa also known as female bamboo is a tropical clumping bamboo originating from Northeast India. This bamboo species is often used as a food source, in scaffolding, for paper pulp or wood chips. The culms of *B. balcooa* are on average between 12-24 m high and 6-15 cm in diameter. This species does not set seed although flowering is occasionally seen, vegetative propagation techniques are however quite successful and propagules can be easily produced in a span of one year. The list of promising clumps of *B. balcooa* along with the passport data, available at ICFRE institutes has been depicted in Annexure VII.

G. *Bambusa nutans*

B. nutans is a medium-sized woody bamboo which is naturally distributed throughout various states of India, such as Himachal Pradesh, Arunachal Pradesh, and Meghalaya up to an altitude of 1500 m, but also grows well in Orissa, Sikkim, Uttar Pradesh and West Bengal. The average culms can measure 6–15 m in height and 5–10 cm in diameter and are smooth, straight, and thick-walled. They are used for various purposes, including timber, house construction, scaffolding, paper mats, etc. The list of selected promising clumps of *B. nutans* along with the passport data, available at different ICFRE institutes has been presented in Annexure VIII.

H. *Bambusa vulgaris*

B. vulgaris is an open-clump type bamboo species and forms moderately loose clumps and has no thorns. It has lemon-yellow culms with green stripes and dark green leaves. Culms are not straight, not easy to split, inflexible, thick-walled, and initially strong. Superior clumps of *B. vulgaris* have been identified by TFRI, Jabalpur, the detail of which has been given in Annexure IX.

I. *Dendrocalmus hamiltonii*

D. hamiltonii, is a giant clumping bamboo native to the north-east era region. The culms of this species are usually curved and its leaves grow up to 15 inches long. The height is approx. 20 m. This bamboo is also very useful for woodworking and furniture industry. List of superior clumps of *D. hamiltonii*, available at RFRI, Jorhat is presented in Annexure X.

5.4 Mass Propagation of Superior Germplasm

The superior germplasm selected needs to be mass multiplied for field evaluations and deployment for large scale plantations outside the forest areas. The ever increasing demand for bamboo as a raw material requires a regular plantation programme. Availability of quality planting material for raising plantation is essential for meeting such demands. National Bamboo Mission (India) envisaged covering over 0.176 million ha area through bamboo plantations needs over 70 million saplings in future. Considering our need to upscale our bamboo industry like China, demand for new plantation will increase geometrically. Using traditional practice of bamboo propagation with unimproved stock cannot meet the demands of large scale plantations. Also there is need for status checking on available knowledge on bamboo propagation and also the best way of application of available technology to meet this objective.

To start a plantation programme on large scale, we need correct information of flowering of desirable species, best seed collection, storage and germination practices, hi-tech nursery management, etc. Also we have to explore alternate method of propagation through vegetative means using macro- and micro-propagation for desirable species and highly productive and qualitative clones. We need a sustainable propagation programme of quality planting material of bamboo which can support mass plantation. Following are the ways of propagation followed universally in bamboo nurseries

5.4.1 Propagation through seeds

Propagation through seeds is the easiest and simple process of reproduction albeit with an unpredictability in seed availability. Seed propagated plantations maintain genetically variability required for survival of species. Bamboo plantations with broad genetic base from which desirable bamboo clones can be selected to improve productivity. It is essential to maintain seed based bamboo propagation programme in forest. Large-scale plantation consideration needs billions of planting material, which can be met through seed propagation. Traditionally, state forest departments (SFDs) raise seed-based bamboo plantations. Propagation through seed is simple and nurserymen have long experience to handle it, moreover it requires lesser care and maintenance of seedling from germination to establishment stage. Seed can be easily transported, and hence, temporary nurseries are often made near plantation area, which reduces cost of propagation and plantation.

B. bambos is the second most widespread bamboo of India. Its seeds are collected after fruiting and raised in nearby forest nursery during monsoon. Excess naturally regenerated seedlings in previously flowered bamboo forest are transplanted in forest nurseries through wildings.

Bamboo flowers gregariously and dies after profuse fruiting. The seeds abundance generally lasts only for 1-3 years. Bamboo seed viability is poor and reduces drastically after 3-4 months of collection (Thapliyal *et al.*, 2015). Only when the flowering cohorts are clearly identified and documented it may be possible that the next flowering event be predicted and plantations through seeds be planned. Some of the bamboo species (*B. vulgaris, B. balcooa, D. stocksii*) has not been reported to set seeding for such species vegetative methods or tissue culture approaches are suitable for mass multiplication. Indian bamboo has been studied for gregarious flowering and it was found that 70 out of 72 species flower gregariously (Gadgil and Prasad, 1984).

5.4.2 Seed production and bamboo flowering

After going through status of flowering cycle and seed production of important bamboo species in India through literature, old herbarium records, personal observation, bamboo flowering records by NMBA, information available in project completion and status reports of ICFRE, apparently following information is generated:

1. It appears that duration between consecutive gregarious flowerings remains same. This knowledge can be used not only to develop flowering prediction model but also for preparation of large scale propagation plans with long-term view.
2. Most of the important Indian bamboo species have approx. 40-50 years flowering cycle. Flowering cycle of some species is 40-45 years (*D. strictus*) (Thapliyal *et al.*, 2015; Yogeshwar Mishra, Pers. comm), 43-49 years (*B. bamboos*) (Naithani and Sanwal, 2017), 38- 45 years (*M. baccifera*) and 44-48 years (*B. tulda*) (Thapliyal *et al.,* 2015).
3. An interesting trend was noticed among widely distributed and important Indian bamboo species that each species flowered at least once in every decade at different location Table 5.2. It implicates that we can always expect seeds of important bamboo species, which can be used for large scale propagation programme if we were able to maintain a national network with the help of forest department and agencies involved in bamboo.

Gregarious flowering

All plants of a species of bamboo in a certain location flower simultaneously (Fig. 5.6). Even, plants taken from those locations to other places also flower simultaneously, *T. oliveri* originally from Burma, flowered simultaneously in 1940 at different plantations in Calcutta and Dehradun and so happened to *M. baccifera*, synchronous flowering in Garo Hills, Meghalaya & Dehradun. Bamboos die after flowering and fruiting.

Fig. 5.6: (a) *M. baccifera* stand before (2006 and after 2007), (b) gregarious flowering in Garo Hills, Meghalaya.

Table 5.2: Year-wise report of gregarious flowering phenomenon of important bamboo species across India

Bamboo species	Years reported for flowering
Dendrocalamus strictus	1900, 1909-10, 1916-17, 1921,1922, 1930-39, 1944-48, 1962-65, 1972-74, 1985- 88, 2004-6,
Dendrocalamus hamiltonii	1894, 1905, 1910-14, 1972-76, 1987-90, 1996-98, 2001-4, 2006-9
Bambusa bambos	1866, 1889, 1894, 1898-99, 1901, 1912-13, 1922-24,1928-29, 1933-34, 1942-46, 1951-54, 1957- 62, 1969, 1974-76, 1988, 1991-95, 1997, 2004-8, 2014-16
Bambusa tulda	1867-68, 1872, 1884, 1889, 1924-29, 1976-79, 1986-87, 1994, 2008, 2011-12
Bambusa pallida	1986, 1993, 2008-9, 2012
Melocanna baccifera	1815, 1863, 1902, 1910-12, 1933,1958-60, 1967, 2000-2008
Ochlandra travancoria	1976, 1988, 1992-93
Oxytenanthera parviflora	1961, 1987, 2008

Source: (Yogeshwar Mishra, Pers. comm.; Naithani and Sanwal, 2017; Thakur and Tanti, 2009; Thapliyal *et al*., 2015).

Seed orchards can be raised for species that flower sporadically in order to ensure increased supply of quality seeds; this can be done by raising blocks of plantations of known seed year, in a series.

5.4.3 Production of quality planting material from seeds

Propagation of bamboo through seed has not been considered as a reliable and sustainable propagation method for due to unpredictable and long intervals of flowering and fruiting. Also seed loose viability quickly (1-3 months) in natural conditions. Most nurserymen prefer to sow it fresh (Banik, 1980). Recently, plenty of work has been done for storage of bamboo seeds and ICFRE and other research institutes has developed longer storage protocol which requires low temperature facilities (Thapliyal *et al.*, 2015).

Gregarious flowering in bamboo is considered as a bane because seeds are available profusely but only for a few months after flowering, which is a limiting factor for a sustainable nursery production. Gregarious flowering, if used effectively, may become as boon as well. Gregarious flowering gives an opportunity to unlock unexplored activity in bamboo, *i.e.,* a long-term genetic improvement programme for productivity and qualitative traits. Genetic variation and control can be studied

Through provenance and progeny (seeds of a selected individual) evaluation and heritability and genetic gain can be estimated to be utilized in improvement of base population (Zobel and Talbert, 1984).

Candidate plus clumps method

During gregarious flowering bamboo mother clumps may be selected using 'candidate plus clumps method' across the distribution of flowered species. Selection criteria may be product specific, *i.e.*, long internode for agarbatti, kite and kulfi stick industries or thick wall and small lumen for bamboo furniture and structural uses or high specific gravity for bamboo plywood, panel and flooring industries.

Flowering clumps of bamboo produce seeds next year, so seeds from the selected mother clump can be collected. Bamboo plantation developing from these seeds ensures large genetic base and abundant variation. Representative plants can be managed in field gene bank for genetic conservation and may also be subjected to provenance and progeny trial as well for estimation of genetic gain and heritability, which subsequently may be used to select 'elite' (genetically improved material)' material. Elite material could be multiplied vegetatively to be used in production plantation as well as base population for future improvement programme. These gains from selection may further be used up to next flowering, which is approx. 40 years.

At ICFRE, a seed-based genetic conservation and improvement programme of M. baccifera was started during gregarious flowering from 2006-10 (Thakur and Tanti, 2009; Tripathi *et al.*, 2011; Thakur *et al.*, 2015). Flowering survey was conducted in *M. baccifera* growing area, *viz.*, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura and 18 distinct provenances were selected across six states. Next year seeds were collected from selected 112 candidate plus clump from 18 provenances and labelled. Best germination (82 per cent) was obtained from provenance of Tripura and least (23 per cent) from Mizoram (Thakur and Tanti, 2009). These selected planting materials representing vast growing area can be base population for future selection.

Seedling selection method

Banik (1997) suggested 'seedling selection method' for production of quality planting material for *B. tulda* and B. *polymorpha*. Seedling from bulked seed are raised, only the best performers are selected based on certain desired morphological characters. Best performers are established in a centralized germplasm bank-cum-vegetative multiplication garden followed by clonal propagation. Gregarious flowering also affects germplasm banks where improved planting material is maintained for clonal production, clumps of same species flowers simultaneously and dies next year and this loss of planting material is considered to be a hazard for clonal genetic improvement programme. An opportunity has been noticed in case of seeds of selected clones are viable. Seeds are half sib progenies so they retain improved character at least by 50 per cent. Planting material developed from these seed can also be used as quality planting material.

5.5 Propagation through Vegetative Methods

During non-flowering period, propagation of bamboo is carried out through vegetative propagation. Propagation through vegetative means is also dubbed as clonal propagation and is suitable to multiply desirable bamboo genotypes in large number to produce quality planting material. Vegetative propagation methods are further divided in two broad segments i.e., macro- and micro-propagation. Under macropropagation offset planting, rhizome, splitting, culm and branch cuttings and layering are used while in micro-propagation techniques like clonal propagation through axillary and meristematic bud proliferation and multiplication by somatic embryogenesis and organogenesis are employed. The oldest report of macropropagation in bamboo is on rooting of cuttings of 3-5 year old culms of *D. strictus*.

From the nineties onwards, emphasis was given on high yielding quality planting material of bamboo by ICFRE, NMBA and NBM. Plus clumps of important sympodial bamboo species were selected in genetic improvement programme. Explants from selected germplasm (ortet) are taken and multiplied using prevalent techniques of micro and macropropagation while maintaining its genotypic identity. There are no universal techniques for vegetative propagation of bamboo. It varies between species to species and most reliable technique was propagation through rhizome and offsets. Most of the germplasm banks were established during nineties using rhizome and offsets. There are no universal techniques for vegetative propagation of bamboo. It varies among species and most reliable technique of propagation is through rhizomes and offsets. Hence, during nineties germplasm banks were established using this material.

Macro-propagation is considered as an easily applicable method for vegetative propagation of plants.. Most of the important Indian bamboo species respond differentially to various methods of macro-propagation Table 5.3, which have been discussed in brief in following paragraphs.

"Lack of availability of proper planting material among farmers and absence of proper grading and storage facilities hamper procurement of bamboo by industries. Bamboo takes greater time and effort when compared to its timber counterparts for production of furniture and construction components. This makes the end product relatively expensive thereby making bamboo based products difficult to compete. There is a need for aggressive use of bamboo products by the Government along with reduction in taxes in the initial years, which can generate interest amongst the buyers, thereby encouraging both manufacturers and farmers to grow and utilize bamboos"

- Sanjeev Karpe, CEO, KonBac, Kudal, Maharashtra

Table 5.3: Amenability of macropropagation method and rooting success of some important bamboo species

S.No.	Species	Rooting (%)		
		Culm cutting	Branch cutting	Layering
1.	*Bambusa Bambos*	70-80	80	Yes
2.	*Bambusa nutans*	70-80	< 30	Yes
3.	*Bambusa tulda*	40-50	< 30	Yes
4.	*Bambusa balcooa*	50-60	70	N.A.
5.	*Bambusa vulgaris*	> 70	> 75	N.A.
6.	*Bambusa pallida*	>60	N.A.	N.A.
7.	*Bambusa polymorpha*	>60	N.A.	N.A.
8.	*Dendrocalamus asper*	60-80	50	N.A.
9.	*Dendrocalamus somdevai*	60-80	>60	N.A.
10.	*Dendrocalamus bandisii*	>70	N.A.	N.A.
11	*Dendrocalamus strictus*	25-40	< 25	N.A.
12	*Dendrocalamus stocksii*	> 70	N.A.	N.A.
13	*Dendrocalamus giganteus*	>60	N.A.	Yes
14	*Gigantochloa atter*	>70	<40	N.A.
15	*Melocanna baccifera*	>60	N.A.	N.A.
16	*Oxytenanthera parviflora*	>50	N.A.	N.A.
17	*Schizostachyum dullooa*	> 60	N.A.	N.A.
18	*Thyrsostachys oliveri*	>60	N.A.	N.A.

(Source: Gulabrao *et al.*, 2012; Kaushal *et al*, 2011 a & b; Raveendran *et al.*, 2010 a & b; Singh *et al.*, 2006; Kaushal and Rana, 2007; Seethalaksmi, 2015; Banik, 1995) ; N.A.: Information not available

5.5.1 Macro-proliferation

During early 1990s, this technique was standardized in plant physiology discipline of FRI (Kumar, 1991). This method includes splitting of rhizomes from seedlings from second years onward and could be done twice in a year (Fig. 5.7). In *B. bambos* and *B. tulda*, reported rate of multiplication rate was 3.5 and 2.5 per year while in *A. falcata* (gol ringal) multiplication rate up to six per year was obtained. This technique is so simple and that it became a universal technique of mass multiplication. Also, rhizome splitting can be continued at least for 5 years or 10 multiplication cycles (Banik, 1995). In tissue culture raised plantlets of *D. asper, B. balcooa* and *B. nutans* this technique is being applied to reduce cost and increase of clonal planting stock by 2-3 times a year.

Fig. 5.7: Macro-proliferation of *Dendrocalamus strictus* by culm splitting

5.5.2 Offset planting

An offset is the base of a single culm with the rhizome axis and roots, mostly from 1-2 years old culms from periphery of a clump are selected. This method is laborious and rate of multiplication is slow and hence, not much in demand these days. It is mostly used for establishment as mother plant in a germplasm bank (Banik, 1995).

5.5.3 Rhizome cutting

In monopodial bamboos, cutting is prepared with sections of fresh living rhizomes with at least a bud of the preceding year along with a portion of the 30 cm long culm (Seethalakshmi, 2015).

5.5.4 Culm cutting

This method has been proven useful for thick wall bamboo species such as *B. nutans, B. tulda*, etc. (Banik, 1995; Seethalakshmi, 2015). From healthy clump, 2-3 years old single culm is harvested and cleaned. From this culm, 1-3 noded cuttings are prepared and treated with auxin, mostly with 100 ppm NAA. In case of single node culm cutting, cutting dipped in 100 ppm NAA for 24 hours before planting and propagated either horizontally and vertically. In case of culm with 2-3 nodes, a cavity is made in the middle of culm and approx. 100 ml NAA (100 ppm) is poured and cavity is sealed (Fig. 5.8). In case of solid bamboos like *D. stocksii* and *D. strictus* instead of making cavity, bamboo is dipped in auxin in big vessel and sometimes applied on nodes with help of cotton (Fig. 5.9). Culms are planted in the bed horizontally, followed by adequate misting.

Fig. 5.8: Propagation method of thick-walled bamboo (*Bambusa nutans*) using binodal culm

Fig. 5.9: Propagation of solid bamboo (*Dendrocalamus stocksii*) using bi-nodal culm cutting

5.5.5 Branch cutting

Bamboo with small lumen or solid stem with stout branches is ideal for branch cutting. It is being successfully used for species like *B. balcooa, B. vulgaris, G. angustifolia, D. somdevai,* and *D. asper. Long* (up to 1 m) branches with 2-5 nodes are harvested from culm and the branch is trimmed to 2-6 nodes followed by treatment with auxins. Branch cuttings are planted at least 7-8 cm deep into nursery bed. After 30-60 days, rooting occurs for cuttings planted during June to August in north India and during April-August in North-East India (Fig. 5.10). This is a quick method of macropropagation but only limitation is time taken (12-30 months) for rhizome development (Banik, 1995).

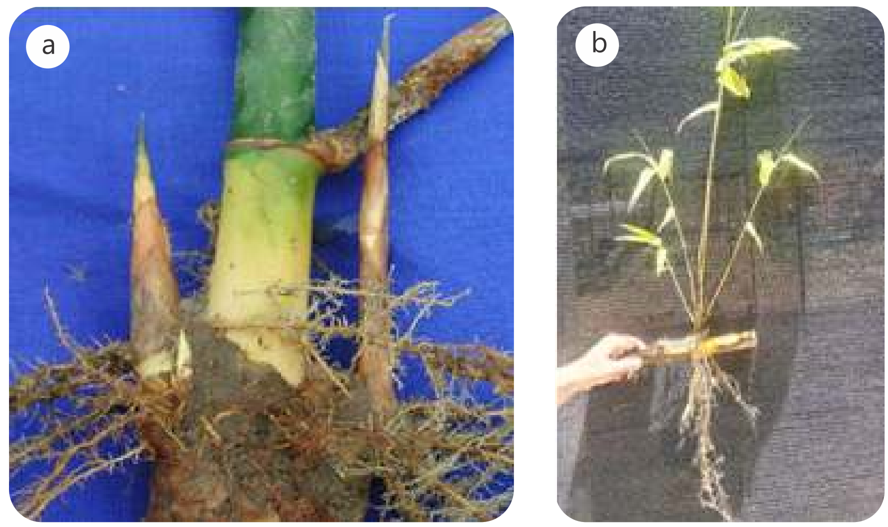


Fig. 5.10: Rooted branch cutting of (a) *B. balcooa* and (b) *B. vulgaris*.

5.4.6 Air layering or markotting

A culm or a branch is slightly wounded at nodes and tightly wrapped with moist rooting medium while attached to the mother plant. Application of auxins on wound sometimes gives better rooting. It is an alternate method of macropropagation but generally not used by the nurserymen.

5.6 Micro-propagation

Micro-propagation has been identified as suitable alternative for rapid and large-scale plant production using small amount of explants. Most of the protocols developed involve seed/seedling derived explants, which ensure high genetic diversity as well as longevity of vegetative growth. For bamboos different approaches of micro-propagation are employed, which are being discussed as follows:

5.6.1 Micro-propagation from juvenile explants

Nadgir *et al.* (1984) reported plantlet production from seedling shoot explants by axillary branching from 15-20 day-old young seedling explant of *D. strictus*. Dekkers and Rao (1989) obtained multiple shoots in *B. ventricosa* using nodal explants. Saxena (1990) reported protocol for the in vitro propagation of *B. tulda* through shoot proliferation of aseptically grown seedlings. Gurumurthi *et al*. (1995) showed that in *B. bambos* seed, quality and seedling vigour can be exploited in consonance with cost-effective tissue culture technique to mass produce the quality planting materials. Arya and Sharma (1998) developed a tissue culture technology for large scale multiplication of *B. bambos* using nodal segments from nursery raised three- year-old plants as a source material. Arya and Arya (1999 and 2002) reported multiple shoot formation in *D. asper* from seeds with 100 per cent rooting and 95-100 per cent plants survival was obtained after hardening.

5.6.2 Micro-propagation from mature explants

Recently, methods for large-scale propagation of bamboos using nodal explants containing axillary bud derived from mature clumps have been reported. Banik (1987) achieved micro-propagation of *B. glaucescens* using culm buds, derived from mature culms, inoculated on MS basal medium containing 10 mg/l BA and 3.0 mg/l activated charcoal. In *D. strictus*, Nadgir *et al.* (1984) obtained shoot proliferation (2-3 shoots from one node) in 80 per cent of the cultures on semi-solid MS medium in 2-4 weeks. About 20 per cent of the shoots rooted when incubated for 96 hours in the dark in Murashige and Skoog (MS) medium containing 4.9 μM indole butyric acid (IBA) and then transferred to solid medium containing 0.25 per cent activated charcoal.

Sood *et al.* (1994) obtained direct shoot regeneration and plantlet production in *D. hamiltonii*. Buds from nodal explants sprouted (occasionally 3-4) within 10 days and grew to 3-4 cm in 3 weeks on half strength MS medium containing 5 per cent sucrose and 0.8 per cent agar. These axillary shoots were excised and cultured in liquid MS medium containing 0.44 µM BAP+4.52µM2, 4-D. The shoots produced were rooted in half strength MS medium containing 2.46-4.9 µM IBA + 2.69 µM naphthalene acetic acid (NAA). Saxena and Bhojwani (1993) reported in vitro clonal multiplication of 4-year-old *D. longispathus*. Rout and Das (1994) cultured segments with small dormant nodal buds collected from the secondary and tertiary branches of Bambusa vulgaris in MS medium supplemented with 12.32µM benzyl aminopurine (BAP) and 54.29 µM adenine sulphate. The buds sprouted and grew upto 1-2 cm in 8-10 days, and 3-4 shoots per nodal explant developed in 2 weeks. Arya and Sharma (1998) obtained 5-fold multiplication rate of B. bambos using nodal segments on MS medium supplemented with 3.0 mg/l BA. Eighty to eighty five per cent rooting was achieved within 20 days on MS medium containing 3.0 mg/l NAA. Arya and Arya (1997) and Arya et al. (1999 & 2002) reported complete protocol for the micro-propagation of six economically important bamboos, namely *D. asper, D. membranaceus, D. strictus, D. giganteus, B. bambos* and *B. vulgaris* from mature clumps. Use of explants from mature clumps permits the selection of plus clumps. But, being a vegetative propagation method, the plantlets produced may also flower along with their parent clumps and therefore, care is to be taken that selected clumps of known physiological age and early in the flowering cycle is used for mass propagation.

5.6.3 Somatic embryogenesis

Micro-propagation via somatic embryogenesis offers another easy method for mass propagation which maintains juvenile period. Different kinds of juvenile and mature material have been used for formation of callus and somatic embryo in bamboo. Alexander and Rao (1968) were the first to report aseptic germination of bamboo seeds of cross specific hybrid bamboo (Bambusa × Saccharum). Somatic embryogenesis and plantlet regeneration are reported in several species of bamboos, *viz., B. bambos* (Mehta *et al.*, 1982; Rao and Rao, 1990), *B. vulgaris, D. giganteus* and *D. strictus* (Rout and Das, 1994), *D. strictus* (Rao *et al.,* 1985; 1990; Dekkers and Rao, 1989; Mascarenhas *et al.*, 1990; Rao and Rao, 1990; Zamora and Gruezo, 1990; 1991; Saxena and Dhawan, 1999), *D. longispathus* (Saxena and Bhojwani, 1993), *D. hamiltonii* (Godbole *et al.,* 2002, 2004), *D. asper* (Kanyaratt, 1991; Arya *et al.*, 2005), *D. asper* (Satsangi *et al.,* 2001), *Drepanostachyum falcatum* (Sharma *et al.*, 2005). Somatic embryogenesis offers the potential for automation and scale up of plant production to much higher numbers than the other methods but the current level of protocols does not permit that since the efficiency of regeneration is very low and the risk of somaclonal variation cannot be ruled out.

5.6.4 Somatic organogenesis

Zamora *et al.* (1990) reported micropropagation of *D. latiflorus* through node and callus culture. Rooting and rhizome formation occurred on 0.5-1.0 mg/l IBA. After hardening, plantlets were successfully established in soil.

5.6.5 Field performance of micro-propagated plantlets

Field performance is the ultimate step for successful utilization of micro-propagated bamboo plant. This starts with a robust hardening protocol of transferring small plantlets (3-5 cm) into plantable seedlings (30-50 cm). Bag *et al.* (2000) tested comparative field performance of in vitro and seedling raised plants of *Thamnocalamus spathiflorus* and found that in vitro propagated plants of *T. spathiflorus* are morphologically as well as functionally comparable to seed raised plants of the same age. Sood *et al.* (2002) evaluated comparative field performance of in-vitro and cutting raised plants of *D.hamiltonii* for six years and concluded that the growth of in vitro propagated plants were significantly better than cutting raised plants. Shrivastava *et al.* (2008) observed altitudinal variations in growth and performance of two species of bamboos in vitro raised *viz., D. strictus* and *B. bambos* in Gujarat and Rajasthan. Rathore *et al.* (2009) tried multi location trial of in vitro raised five species of bamboo, *viz., B. balcooa, B. bambos, D. asper, D. stocksii* and *D. strictus* in south India and observed that *B. balcooa* as one of the most promising species in terms of height and *D. asper* was recorded with the maximum culm number. Mishra *et al.* (2015) evaluated tissue culture raised plants of *B. nutans, B. tulda* and *D. asper* at Jabalpur. After 2 years of plantation, *B. nutans* emerged as a species with maximum response to micro-propagation while recording maximum culm number and diameter growth.

5.7 Multiplication Strategies for High Yielding Bamboo Germplasm

Phenotypically superior germplasm is available at various research and development organisations in the country and the material is under various stages of testing. Ideally, multiplication of superior material should begin after field evaluation. However, multiplication of a new clone into significant numbers, to be of practical use in largescale planting programme, needs several cycles of multiplication spanning many years. The approach of multi-step selection and concurrent multiplication (Kumar and Singh, 2001) comes handy in such a situation which advocates that multiplication and field evaluation go hand in hand coupled with narrowing down of the list of clones under multiplication. For achieving early multiplication of the most productive clones of a tree for six-year rotation age for deployment, this approach suggested that multiplication should be started with the best 60 per cent clones selected at age 2 years. Culling could be done to reduce the number of clones under multiplication in nursery to 33 per cent, 13 per cent and 5 per cent after age 3, 4, and 5 years, respectively. The requirement of nursery resources for progressively propagating the select clones was found to be in the order of age 2 < age 3 < age 4 < age 5 implying that the technique is practically feasible and resource friendly too.Therefore, multiplication of promising material already available with research bodies must be started immediately by adopting the approach of multi-step selection and concurrent multiplication to expeditiously supply improved plants to growers.

5.7.1 Strategy for quality planting material from seed

Sustainable production of quality planting material through seed is possible if a national framework including all stakeholders can be prepared embedding all information generated through research and technology. This can help in converting gregarious flowering from bane to boon, if we start a seed-based genetic improvement programme as mentioned in section 2.1. Between 2006 to 2017, there have been reports of gregarious flowering in important bamboo species of India, *viz., D. strictus* (2004-2006), *D. hamiltonii* (2006-2009), *B. bambos* (2004-2008 and 2014-2016), *B. tulda* (2008 and 2011-2012), *B. pallida* (2012), at different locations, which could have been used for nursery production of bamboo through genetically improved (Table. 5.1). Seed storage research has developed technology to increase shelf life for seeds up to three years (Thapliyal *et al.*, 2015). This knowledge may be used by creating a central seed storage facility with regional centres, so that viable seeds can be stored for long term and further supplied to nurseries to be used as quality planting material for sustainable nursery production. A flow chart for proposed facilitation of sustainable production of quality planting material through seed based on available information is being described in (Fig. 5.11). After eight years, selected material further multiplied through vegetative propagation. Usually flowering is reported during each decade for important bamboo species and hence new propagation schedule may be initiated Table 5.2.

Time scale (year)	**Sustainable Quality Planting Material Production Cycle**	
0	Flowering report through network Selection of superior plus clumps	Seeds from flowered clumps in improved germplasm banks
1	Collection of seed from selected clumps in next year and 1-3 years storage in low temperature storage facilities	
1-3	Nursery from fresh/ stored seed	
2-8	Further multiplication through macro-proliferation (2-5 years)	
	Using proposed technology, sustainable production of quality planting material for 7 year from one flowering phenomenon	

Fig. 5.11: Action plan for sustainable production of quality planting material in nurseries for 8 years continuously from single year's seed collection

5.7.2 Clonal propagation of bamboos through macro-propagation

Although bamboo can be conveniently propagated through seed, it is suggested that improved planting stock of clonal origin should be used to the maximum while establishing new plantations; this would ensure uniformity of the raw material, easy harvest and higher productivity. Successful protocols (per cent) have been developed for different plant multiplication rates through culm and branch cuttings:

Bambusa nutans	-	> 80
Bambusa tulda	-	50-60
Bambusa vulgaris	-	70-80
Dendrocalamus somdevaii	-	70-80
Dendrocalamus strictus	-	up to 50

At FRI approx. 4000 quality germplasm of selected bamboo species are ready to serve as mother stock. Central Nursery, FRI produced more than 25,000 plants of QPM within one year. From this mother stock, micro-propagation has been started so that high yielding quality planting material could be multiplied en masse.

Three tissue culture laboratories of ICFRE at FRI, Dehradun, TFRI, Jabalpur and RFRI, Jorhat started mass production of quality germplasm of selected bamboo species. Micro-propagation is started from abovementioned mother stock from each participating Institutes. Under this programme clone specific micro-propagation protocols have been developed for total 14 quality germplasm of *D. asper, B. nutans, B. balcooa, B. tulda* and *B. vulgaris* var. green. This is a networking programme so participating Institutes is sharing material. By this, we do not only maintain master culture at different places but also fine tune production process and share knowledge with each other. Successful production protocols of 16 selected clones of five species was achieved in 18 months (Table 5.4). The programme will continue till December 2018 with an objective to produce more than 50, 000 plants. The multiplication rates using the common protocols for various species are given in Table 5.5.

Table 5.4: Micro-propagation of selected accessions (clones) of bamboo

Species	Accession Number of QPM	Plants ready	Culture bottles ready for future multplication and rooting*
FRI, Dehradun			
Dendrocalamus asper	DAS 1	1200	10
Bambusa balcooa	585	200	800
Bambusa nutan	TFRI-1	-	105
Bambusa tulda	OR-GHA 1	-	40
Dendrocalamus strictus	-		15
RFRI, Jorhat	-		-
Bambusabalcooa	578 and 585	1500	200
Bambusa nutan	656 and 642	-	200
Bambusa tulda	469, A-20 and 480	1500	300
TFRI, Jabalpur			-
Bambusa nutans	TFRI-1 and TFRI-2	450	250
Bambusa tulda	OR KO-1, OR-GHA 1, 2 and 4, MP-TF 1	350	150
Bambusa balcooa	TFRI-1 and SFRI 1,	600	75
Bambusa vulgaris	MP-TFSIL 1 and CG-5	450	125
	Total	**6250**	**2270**

*each bottle contains 3-5 plantlets, which keep multiplying in geometrical progression. Fifty per cent of multiplied material is further multiplied and balance is transferred for rooting.

Table 5.5: Commercial scale production of *B. vulgaris* (green and yellow), *B. tulda* reported by IFGTB) Coimbatore.

Bamboo species	Rate of multiplication	Bamboo species	Rate of multiplication
Bambusa tulda	1: 25	*Bambusa vulgaris* (green)	1: 12
Bambusa nutans	1: 30	*Bambusa vulgaris* (yellow)	1: 15

Certification of planting material is of immense importance for promoting large-scale plantation. An approach for certification of bamboo planting material has been suggested (KFRI 2014, http://nbm.nic.in/PDF/CertificationNBM15.05.2014.pdf).

5.8 Establishment of Modern Nurseries

Large nurseries of priority bamboo species need to be established in the bamboo growing areas by the SFDs, forestry research organizations, industries, NGOs, communities and individuals, to ensure production of quality planting stock.

There is dearth of modern nursery of bamboo in both government and private sector. In government sector, five nurseries of ICFRE institute (Fig. 5.12); FRI, TFRI, IFGTB, RFRI and IWST have annual production capacity of 50,000 to 1,00,000 plants. These nurseries have good facilities but can be enhanced by incorporating intelligent and automated system and precise nursery management. These nurseries, by virtue of the research support of ICFRE, have the potential of becoming source of superior quality mother plants.

Fig. 5.12: Nursery facilities available at ICFRE institutes

In private sector, GrowMore Biotech, Hosur, Tamil Nadu is multiplying following bamboo species through micro-propagation (http://www.growmorebiotech.com/bamboovarities.htm): *B. balcooa* :

Bambusa nutans	*Bambusa tulda*	*Bambusa vulgaris*
Bambusa bambos	*Bambusa polymorpha.*	*Dendrocalamus asper*
Dendrocalamus strictus	*Dendrocalamus hamiltonii*	*Dendrocalamus giganteus*
Dendrocalamus stocksii	*Oxytenanthera travancorica*	*Thyrsostachys oliveri*
Pleioblastus variegates	*Pleioblastus distichus*	

However, the expertise and the installed capacity in the country for large-scale micro-propagation is tremendous that can be effectively utilized for rapid multiplication and deployment of superior planting material. Quality control through the National Certification System for Tissue Culture Raise Plants (NCS-TCP) of DBT (http://www.dbtncstcp.nic.in/) is also of advantage in this context. A manual on nurseries has been prepared by KFRI (2014) and is available at http://nbm.nic.in/PDF/Manual19.5.14.pdf.

5.9 Genetic Resource Conservation

Genetic improvement and conservation are complementary to each other. In- situ and ex-situ conservation, can contribute significantly to improvement programme by providing sustainable source of genetic material. Both in-situ and ex-situ conservation measures are being adopted to preserve the genetic resources of bamboos. In-situ conservation measures include establishment of preservation plots, where the biodiversity including bamboos is being periodically monitored. The ex-situ conservation activities for preservation of important genetic resources of bamboo are limited to establishment of germplasm banks and bambusetums. Following description gives an account of some germplasm banks and bambusetums established across India that contribute to conservation of the valuable genetic resource. Such facilities must be strengthened and maintained for future.

5.9.1 Germplasm banks

A programme was developed for reliable multiplication for high yielding bamboo germplasm during 2015-2017 with NBM and BTSG (ICFRE) at different ICFRE institutes. Essential component of programme was germplasm bank development and macropropagation of quality planting material. Elite bamboo germplasm have been selected and planted in germplasm bank of following species at five Institutes of ICFRE *viz.*, FRI, TFRI, IWST, RFRI and IFP

Bambusa nutans	*Bambusa tulda*	*Bambusa vulgaris*	*Bambusa balcooa*
Dendrocalamus somdevaii	*Dendrocalamus hamiltonii*	*Dendrocalamus strictus*	*Dendrocalamus stocksii*

5.9.2 Bambusetums

Bambusetums are special plantations where different species of bamboo are displayed in a small area demonstrating inter-species diversity.

FRI Bambusetum, Dehradun

The bambusetum or bamboo garden of Forest Research Institute was established in 1930s.The development of the bambusetum was a visionary step as in 1930s the forests resources were plenty and the concept of in-situ conservation was not well established. Bambusetum of Forest Research Institute plays an important role in bamboo research and education. It has 34 bamboo species collected from different parts of India, Bangladesh, Myanmar, China, Japan, Malaysia, Indonesia, Thailand and south America, *viz., B. balcooa, B. bambos, B. multiplex, B. nutans, B. tulda, B. vulgaris, D. asper, D. calostachyus, D. longispathus, D. embranaceus, D. strictus, Gigantochloa atroviolacea, Melocalamus maclellandii, M. baccifera, Phyllostachys aurea, Schizostachyum pergracile, Sinarundinaria falcata* and *T. oliveri*.

Further with the support of the NBM, two bambusetums – one for *D. strictus* and the other for hill/temperate bamboo species/ clones at 1800 m altitude was established by the FRI. The germplasm bank of *D. strictus* was established at FRI with the germplasm from 17 states and 15 hill bamboo species were established in Hill bambusetum at Field Research Station, Khirsu in (Pauri Garhwal) during the year 2008-09.

KFRI Bambusetum, Field Research Centre, Velupadam

The KFRI-Bambusetum was established during 1988-95 as part of the IDRC Bamboo project at FRC campus, Veluppadam. 70 different species of bamboos are present in the Bambusetum of this, 63 species are in the Field Research Centre, Velupadam and 8 species (3 of them yet to be identified) in a high elevation site at Devikulam. Valuable information on clump development, Culm production and growth parameters like culm length, culm girth, etc. are being gathered computed and analyzed for productivity of these valuable Bamboos. Effect of management practices like weeding, soil working, selective cutting etc. on the production potential of each of these species is being closely monitored. The KFRI-Bambusetum aims to have an exhaustive collection of sympodial bamboos that can be grown in a typical agro-climatic zone and to gather invaluable scientific information on bamboo growth in state. The Bambusetum also serves as genetic resource for future crop improvement programmes and for forest managers and farmers. Recently interspecific hybridization was undertaken in KFRI Bambusetum when synchronous flowering was observed in the collections. List of bamboo species at FRC, Veluppadam.

Bambusetum, Devikulam

The bamboo species at the high elevation site at Devikulam (9 species) include *Phyllostachys bambusoides, P. assamica, P. sulphurea, P. pubescence, P. reticulata*, and three other unidentified species.

Bambusetum, Nilambur

Bambusetum at KFRI Sub-Centre, Nilambur is a gene bank conservation area with over 50 species. The important ones are listed in Annexure QPM.

Bambusetum, JNTBGRI, Palode

The largest in India bambusetum at JNTBGRI, Palode, spread over an area 6.59 ha houses 954 accessions belonging to 69 species and 1 variety under 15 genera, in addition to 12 hybrids produced by the Institute. JNTBGRI maintains diverse bamboo species and their different hereditary lines along with records of their pheno-events such as growth, flowering, fruiting, death and details on progenies. Species from India (Western Ghats, north-eastern region, Andamans), south-east Asia, Japan and south America are represented in the Bambusetum. It contains curious species like the giant bamboo *D. giganteus, the south American G. angustifolia,* the rare zig-zag bamboo *D. macclellandii,* climbing bamboo *Dinochloa andamanica* and *M. compactiflorus* and many more. The live collection opens a wonderful world of bamboos to the visitors. The genera and number of species represented are: *Bambusa* (14), *Cephalostachyum* (1), *Dendrocalamus* (17), *Dinochloa* (3), *Gigantochloa (4), Guadua* (1), *Melocalamus* (1), *Melocanna* (1), *Ochlandra* (13), *Phyllostachys* (4), *Pseudoxytenanthera* (6), *Sasa* (1), *Schizostachyum* (1), *Shibataea* (1) *and Thyrsostachys* (1).

JNTBGRI Bambusetum, apart from being supportive in addressing the needs of the state and enhancing scientific knowledge on various bamboo species, is also functioning as a demo plot of various species, as a nursery supplying planting materials of required species, as a field laboratory to carryout scientific observations such as studying morphologic characters useful in taxonomy, determining the flowering cycles, conducting breeding trials and thus, paving ways for multidisciplinary studies on bamboos. It also demonstrates how a live collection of bamboos can be used to disseminate interest in various aspects of an economically important group of plants by involving researchers, farmers and local communities. It is useful to all who are concerned with conservation of genetic resources of bamboos. Its detailed history and inventory of its collections are available in a classical work of Koshy (2010).

Germplasm banks of Tamilnadu Forest Department

Tamil Nadu forest department established bamboo germplasm in various parts of the state wherein nearly 40 bamboo species were assembled. Bamboo germplasm banks are available at following TNFD research and extension centres, which serve both as germplasm bank and active clonal multiplication centres:

a) Amaravathi
b) Bhavani Sagar
c) Coimbatore Genetic Range Hq.
d) Erumadu
e) Gene Pool Garden, Nadukan
f) Kolapakkam
g) Kumbakonam
h) Mukkombu
I) Neyveli
j) Seshan Chavadi
k) Varattupallam
l) Vilamundi, and
m) Walavayal

Based on the growth performance of various introduced bamboo species in the state, around 5 thorn-free bamboos species were promoted. The main species promoted were *B. balcooa, B. tulda, B. nutans, B. vulgaris* and *D. strictus*. These germplasm assemblages are species assemblages and do not contain individuals selected for higher productivity or desirable character. However, the assemblages are utilized in planting stock production through clonal route for the farmers.

Germplasm Banks, IFGTB, Coimbatore

Germplasm bank has been established by IFGTB Coimbatore with bamboos species collected from KFRI, Tropical Botanical

Garden Research Institute, IWST, RFRI and Tamilnadu and Karnataka Forest Departments. Presently the germplasm assemblage has 90 accessions covering 25 species.

Germplasm Bank and Multiplication Garden, IFGTB, Kurichi, Coimbatore

The germplasm bank, of IFGTB contains 93 accessions of 34 species, while bamboo multiplication garden has 51 accessions of 25 species. After establishment of Forest Genetic Resource Management Network (FGRMN), more germplasm were collected from Arunachal Pradesh, Assam, Uttarakhand, West Bengal, Karnataka, Kerala and Tamil Nadu.

Bamboo Germplasm Bank, IWST, Bengaluru

IWST, Bengaluru has established CPCs of *B. bambos, D. strictus, P. stocksii* and *D. brandisii* in the form of germplasm banks at Gottipura field station in 2006. Gregarious flowering has occurred in *D. brandisii* base population in Coorg Karnataka and in the CPC's that were planted in the germplasm bank at Gottipura, IWST during 2012-2014 period. After the gregarious flowering, the seeds have been collected from the flowered CPCs and their seedlings have been raised. (Fig. 5.13). The seedling populations will be used for building the base population and selection of new clumps in future. The current status and review of germplasm bank at Gottipura. Field Station of IWST.

Fig. 5.13: Top row (L to R) Flowering of *D. brandisii* CPC in Coorg, Close-up of flowering culm; Bottom row (L to R) close-up of seeds collected, Seedlings of *D. brandisii* raised in IWST nursery

- **Germplasm Bank, TFRI, Jabalpur**

Tropical Forest Research Institute (TFRI) has established a germplasm bank (Fig. 5.14), comprising four species, *viz., B. tulda, B.bamboos, B.vulgaris var.* green and *D. strictus*. Besides, some germplasm of *B. nutans, D. longispathus* and *B. balcooa* have also been added in the germplasm bank.

Fig. 5.14: Germplasm bank of bamboo species at TFRI, Jabalpur.

- **Germplasm Bank and Bambusetum, RFRI, Jorhat**

RFRI has been working in the area of bamboo research since 1990. During 1998 to 1999 RFRI, carried out intensive survey to select superior clone (genotypes) from Assam and parts of Meghalaya. A total of 1355 clumps of six commercially important species, *viz., B. bambos, B. balcooa, B. tulda, B. nutans, B. pallida* and *D. hamiltonii* were evaluated for growth performance in homestead garden and forest areas and 249 promising clumps were selected and established in germplasm bank. However, some of them could not survive and again in 2008-2009 selections were made and 93 CPCs were collected and established in the germplasm bank. RFRI has also established a Bambusetum where 47 species of bamboo have been conserved. Likewise other research institutes and forest departments in north-east India have established bambusetum in their respective states. However, the bambusetums that have been established at various places in Northeast India were designed as mere representative species collection. The ranges of genetic diversity of a species have never been taken into consideration and hence they cannot be regarded as gene bank.

- **Bambusetum, SFRI, Itanagar**

In north-east India conservation and improvement programme in a systematic way first started at Van Vigyan Kendra (VVK), Chessa under the SFRI, Itanagar in 1980s. From 1981 to 1983 VVK, Chessa carried out selection of promising genotypes from different region of Arunachal Pradesh and added 35 different species of bamboos in a bambusetum. Currently, there are 56 species of bamboo in the bambusetum.

- **Bambusetum, IFP, Ranchi**

The bambusetum of Institute of Forest Productivity Ranchi was established in the year 2008 at Lalgutwa with 44 species collected from different parts of country. This is the biggest collection of bamboo species in the states of Bihar and Jharkhand having a well-planned layout.

- **Bambusetum, TFRI, Jabalpur**

Bambusetum of TFRI was established during the year 1984-1986. During the World Bank FREE project, it was enriched with more bamboo species and presently it has 14 species of 2 genera.

- **Bambusetum, SFRI, Jabalpur**

The bambusetum was created during the year 1983-1985. Presently, It has 10 genera and 19 species of bamboo.

5.10 Summary

Bamboo improvement work in India is still in infancy. To meet the indigenous demand, plantations outside the forest are viable alternatives to meet the growing demand. However, there is severe scarcity of the selected planting material of bamboos for higher productivity for large scale plantation programme. Non-uniformity of bamboo germplasm available for plantation programs is one of the main issues coming in the way of enhancing bamboo productivity. Very little information is available on the selection of candidate clumps of a bamboo species. Some initiatives were taken in past on genetic resource conservation and selection of plus clumps of important bamboo species, *viz., B. balcooa, B. nutans, B. pallida, B. tulda, D. giganteus* and *D. hamiltonii* in a limited manner mainly by SFRI, Itanagar and some ICFRE institutes. However, these works never gained priority and were not carried out in a continuous process. Moreover, the activities on bamboo remained limited to establishment of bambusetum and germplasm banks. Under the World Bank FREE project, efforts were taken by ICFRE in collaboration with several other research organizations to identify and collect promising genetic resources of the important bamboo species. The lack of continuity after the project further jeopardized the evaluation, multiplication and dissemination of the selected germplasm in different agro-climatic zones.

Considering the importance of the improved germplasm of bamboos, National Bamboo Mission during the year 2013, awarded a network project to FRI-ICFRE for bamboo genetic evaluation improvement and propagation. The project was executed in the year 2014 across the country through five ICFRE institutes, *viz.*, FRI, TFRI, IWST, IFP, and RFRI on ten commercially important bamboo species, *viz., D. strictus, B. bambos, B. vulgaris, B. tulda, B. nutans, B. balcooa, D. hamiltonii, D. stocksii* (= *Pseudoxytenanthera stocksii*), *D. brandisii and D. somdevai*. The evaluation trials of selected bamboo species established in past were revisited across different locations in the country, and evaluated with a set of selection parameters. Promising superior clumps were identified through multi-trait evaluation. This activity has resulted in identification of 289 superior clumps of ten selected bamboo species across in five ICFRE institutes. Now, there is a need to mass multiply the available improved germplasm of selected bamboo species, establish their rhizome banks and disseminate the planting material to various states to harness their potential. This will ultimately help in improvement in form and productivity of bamboo plantations in the country.

Besides, the bamboo genetic conservation programmes is the well accepted component in the country that has been widely initiated by different institution and state forest department in the form of establishment of bambusetum and germplasm banks. These are directed towards the long-term preservation of genetic material either *in-situ* or *ex -situ* to act as a repository or a reference material and further multiplication and improvement.

5.11 Conclusion

India has more area under bamboo than China but it is not able to scale up our bamboo sector. India Bamboo Industry reiterated low availability of quality raw material of bamboo is a major hindrance. To fulfil industrial demand, we have to produce genetically improved and industry specific quality planting material (QPM) of bamboo. QPM production has two essential components viz., selection of desirable clumps and propagation of clumps either through seed or vegetative means. Bamboo seed availability seems to be unpredictable but it is not so. Species having large distribution flowers at least once in a decade. National framework with long term view is essential for production of seed based QPM. In this framework, roles of all stakeholders must be defined. ICFRE may contribute on technology, training and capacity building aspects. Lately vegetative propagation technology of mass multiplication of selected clones of important bamboo species has already been started. Considering there is a large demand of uniform and tested clones, this has to be elevated on mega scale and need to be scaling up to million plants per nursery per year through improvement in technology for mass propagation of bamboos through vegetative propagation methods. particularly micropropagation for which the expertise and capability in the country is adequate. Modern nursery practices and accreditation/certification have to be adopted to economize production of QPM and ensure consistent quality.

CHAPTER - 6

AGROFORESTRY

6.1 Introduction

The National Agroforestry Policy, 2014 defines agroforestry as a land use system, which integrates trees and shrubs on farmlands and rural landscapes to enhance the productivity, profitability, diversity and ecosystem sustainability. It has now been recognized globally that agroforestry has the potential to achieve agro-ecosystem sustainability while optimizing agricultural productivity, profitability and diversity, besides mitigating climate change impact. Due to special status as a 'woody grass', bamboo can play a key role in complementing, if not substituting, the woody tree component in an agroforestry system design. Bamboo is becoming a popular plantation crop due to fast growth and multiple utility. Bamboos are also present in the forest and are part of the non-timber forest produce, which can have significant economic value. In north-east India, where bamboos are abundant, studies have explored the potential of bamboos in agroforestry systems and revealed that it adds extensive utility value to overall rural community development by providing economic, ecological and social stability to farmers in the region.

6.2 Potential as an Agroforestry Crop

To fulfil the requirements of a desirable multipurpose tree species (MPTs) in agroforestry practices, a woody species is expected to yield fuel, leaf fodder, smallwood, timber, edible products or other utility products along with a desirable shape and high growth rate. Due to wide variation in habit (culm and clump characteristics) of the diverse species, bamboo does not fit into the stereotype of an MPT in agroforestry. However, the diversity among the species could be used to match species with site in a given agro-climatic zone. Its recognized properties do qualify it as a favourable species for agroforestry (Fig. 6.1).

> The lack of information on management of bamboos in intercropping systems is a factor that deters farmers from adopting such farming systems.

Bamboo has the perception of occupying large swathes of precious agricultural land and encroaching into adjacent farmlands especially when planted on farm boundaries. This is especially true for *Bambusa bambos* and *Dendrocalamus strictus*. *B. bambos*, in addition to its stated disadvantage, has a thorny nature, often making it a virtual nightmare for the farmers to tackle this species in farmland.

A potential limitation in the integration of bamboo in intercropping systems is its perceived root competition with understorey crops, especially when it is grown in compact block plantations at close spacing. Relatively less information is available on intercropping options under bamboo such as compatibility with crops, optimum planting density and other management options. Understorey productivity in such systems is a function of competitive interaction for light and space.

Yet another less recognized factor affecting crop productivity in bamboo-based agroforestry system is root competition. Absorption of water and nutrient from soil by bamboo also depends on the growth habit of the particular species and efficiency of its roots and rhizomes. Fine roots and root hair of bamboo play an important role in supporting high productivity of bamboo. It is generally accepted that root systems of bamboo do not go beyond a particular soil depth which is usually around 1.0-1.5 m. Bamboo tends to develop a rather profuse mat of highly efficient fine roots within the uppermost soil layer (0-30 cm) and fine root system which rarely extends beyond 40 cm depth. Apart from the high aboveground biomass production, bamboo also stores substantial carbon in belowground parts, *i.e.* rhizomes and roots. Bamboo roots, by virtue of their spreading nature, may thus contribute to enrich soil carbon pool at lower depths, even up to one metre and beyond.

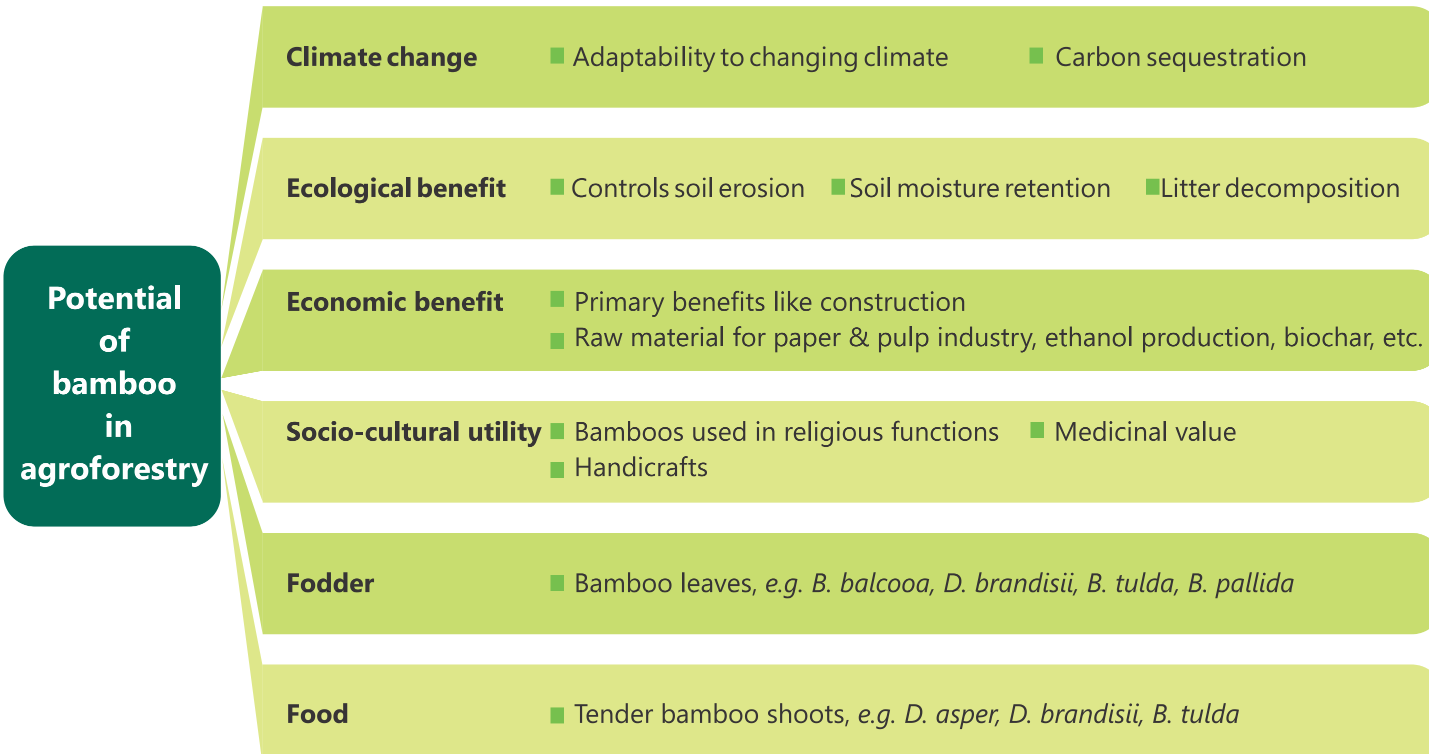


Fig. 6.1: Potential of bamboo in agroforestry

Despite its high biomass production potential and economic value of culms, there is scanty information on biomass production, nutrient accumulation/cycling and litter dynamics of a given species grown under planting regimes in different agro-climatic zones. Bamboo-based agroforestry has immense potential for resource conservation. Sujatha *et al.* (2008) found that the rhizome system of bamboos are interlocking in nature, which along with the fine fibrous root system ensures binding of soil particles thereby reducing soil erosion. Furthermore, due to its inherent physical characteristics like dense foliage and large culms, bamboos can intercept more rainfall which, in turn, makes it hydrologically better suited for plantation establishment on stress sites (Rao *et al.*, 2012).

The ecological benefits from bamboo agroforestry systems are many and need to be adequately recognized.

Some species of bamboo like *D. strictus* are especially useful in low rainfall areas. Organic matter from litter decomposition in drought-prone areas helps in absorbing moisture and thereby enhances water availability to plants. Bamboo litter can absorb moisture in the range of 2.7-2.9 times of its dry weight (Zhou *et al.,* 2005). In addition, the fine root system of bamboo enables it to recover nutrients leached into the soil (Christany *et al.,* 1996).

6.3 Agroforestry Systems and Practices

Broadly bamboo-based agroforestry systems reported within the country could be categorized under different agroforestry systems like homesteads, block plantations, wide row intercropping, wind breaks and miscellaneous systems (Fig. 6.2).

6.3.1 In homesteads

Fig. 6.2: (a) *Bambusa tulda* in a homestead in Chessa, Arunachal Pradesh, (b) and *Dendrocalamu stocksii* in Konkan, Maharashtra

In homestead (homegardens), where land is a limiting factor, having a bamboo in the backyard may be perceived as a luxury which farmers can ill-afford. Bamboo species like *D. asper,* which have aesthetic and nutritional values, can be a viable option. Banik (2000) estimated that 15-30 % of the tall tree canopy in the north-eastern States like Assam and Tripura is contributed by bamboos. Another survey done in 13 villages of Madhya Pradesh highlighted that 15.13 % families grew *D. strictus* in their homegardens (Gangopadhyay, 2003). In Uttarakhand, bamboo species like *B. balcooa, B. tulda, B. nutans and D. hamiltonii* are cultivated alongside other multipurpose trees in homesteads. Species such as *Drepanostachyum falcatum* (ghad ringal), *Himalayacalamus falconeri* (deo ringal), *Thamnocalamus spathiflorus* (thaam ringal) and *T. jaunsarensis* (jamura ringal) are much valued by rural communities in Uttarakhand. Table 6.1 depicts prominent bamboo species in different regions and agro-climatic zones.

Table 6.1: Bamboo species suitable for homesteads across regions in India

Zone	Region	Species
Western Ghats (Kerala, Karnataka, Goa and Maharashtra)	Tropical humid	*D. stocksii, D. strictus, B. bambos*
North-East (Arunachal Pradesh, Assam, Meghalaya, Manipur, Mizoram, Tripura, Nagaland)	Tropical humid	*B. balcooa, B. tulda, B. pallida, B. nutans, B. polymorpha*
Central Zone (Madhya Pradesh, Uttar Pradesh, Bihar)	Sub-humid and semi-arid	*D. strictus, B. bambos, B. tulda, B. balcooa*
Eastern Zone (Odisha, West Bengal)	Humid	*B. tulda, B. nutans, B. vulgaris var. green*
Subtropical and Temperate Zone (Himachal Pradesh and Uttarakhand)	Humid	*D. hamiltonii, Drepanostachyum falcatum, Himalayacalamus falconeri, Thamnocalamus spathiflorus, T. jaunsarensis*
Western Dry Zone (western Maharashtra, Punjab)	Semi-arid	*D. strictus, B. bambos*

(Source: Tewari *et al.*, 2015)

6.3.2 Block plantations

In rural areas endowed with assured irrigation facilities and established market outlets, bamboo block plantations can be an income generating farming activity with minimal expenditure on inputs like labour, pesticides and supervision as compared to risk prone highly intensive horticultural species. It is also possible to do this in organic way by exploiting the copious litter fall and enabling its speedy decomposition in well-designed vermicomposting or microbial composting pits created in-situ in the interspaces of bamboo plantations. Generally, 6m x 3m or 5m x 5m spacing is ideal for most mid-sized bamboo species. It may be possible to reduce the spacing further and increase the planting density for species like *D. stocksii* and *Thyrsostachys oliverii* (Fig. 6.3).

Fig. 6.3: Commercial block plantation of *D. stocksii* in a farmer's field in Sindhudurg, Maharashtra

6.3.3 Wide row intercropping

Intercropping under bamboo is generally not very successful due to the fibrous, spreading rooting behaviour in sympodial as well as amphipodial bamboo species. The root system of bamboo does not go beyond 1.5 m depth and the fibrous roots of bamboo has the tendency to spread laterally and compete with the inter-cropped agricultural crops for moisture and nutrients. For successful intercropping in the initial 5-6 years at least, proper ideotype of the bamboo species selected could be the primary criteria. Bamboo species having erect culms with narrow leaves like *D. stocksii, T. oliverii, Oxytenanthera richteyii* are ideal for this purpose.

Fig. 6.4: Intercropping with annual crops in *D. stocksii* bamboo in Wakavalli station in DBSKVV Dapoli, Maharashtra

Bamboos have been planted at varying spacing ranging from 4m x 4m to 9m x 9m in intercropping trials across the country. The spacing is dependent on type of bamboo species and intercropping crop species. Attempts have been made to incorporate *D. stocksii* along with agricultural crops especially in the upland agricultural systems in humid tropics in Dapoli, Maharashtra in Western Ghats (Fig. 6.4). Observations reveal that there is a significant improvement in culm emergence, culm collar diameter and diameter at fifth internode of emerging culms under intercropping (Bhave *et al.*, 2011). Bamboo intercropped with fingermillet annually produced as much as 18 culms per clump while sole bamboo produced around 8 culms per clump only. This indicates better performance of bamboo on intercropping with agricultural crops at least in the initial years as bamboo is able to effectively utilize management inputs given to agriculture crops. Spacing also plays a vital role in determining the yield of the agriculture crop. Though, there is little variation initially in agricultural yield moving away from the base of the clump, that trend is unlikely to continue with age as competition for resources may become more evident and may cause reduction in yield as the clumps get older.

Typically, such intercropping can be done for a maximum of four years after which it is not feasible. Similar intercropping trials have been conducted in sub-humid zones of central India in Jabalpur, Madhya Pradesh. In the initial stages, crops like soybean, mustard, wheat and few pulses can be grown with bamboos. Eventually, as the bamboo grows older, shade tolerant crops like sweet potato become more feasible alternatives. Many bamboo species like *B. bambos, B. nutans* and *D. strictus* have been successfully intercropped with maize and soybean in Jabalpur (Banik, 1997). Few studies in eastern India involving growth of medicinal plants alongside bamboo showed that yield of medicinal plants like Aloe vera, tulsi, etc. declined drastically in bamboo-based agroforestry systems (Banik, 2000; Banik *et al.*, 2008). Studies have also shown that there is an increase in rhizome yield of ginger and turmeric when grown with *D. hamiltonii* and *P. pubescens* (Tewari et al., 2015). A compilation of successful bamboo intercropping trials across India along with spacing adopted and crops grown have been cited for further reference (Table 6.2).

Table 6.2: Few prominent studies on intercropping with different bamboo species in India

Bamboo species	Intercropped with	Region	Spacing	Main observations	Reference
D. asper *B. tulda*	Cowpea	Tarai (Uttarakhand)	5m x 5m	Maximum yield recorded under *D. asper*, closely followed by *B. tulda*	GBPUAT (2010)
D. asper	Soybean	Tarai (Uttarakhand)	5m x5m	Successful if taken as intercrop for first three years	Tewari *et al.* (2015)
B. bambos	Pigeon pea/ soybean/ ginger/turmeric	Tamil Nadu	3m x 3m	Pigeon pea and soybean more productive than ginger and turmeric	Shanmughavel and Francis (2001)
D. brandisii	Paddy	Coorg, Karnataka	6m x 6m	Highest NPV and LEV at the spacing	Viswanath *et al.* (2007)
D. strictus	Cotton	Dharwad, Karnataka	10mx10m; 12mx10m	After first year, yield of cotton reduced drastically	NRCAF (2014)
B. balcooa, *B. tulda*	Paddy/cow pea/groundnut/ pigeon pea/ turmeric	West Bengal	10m x 10m; 12m x 10m	Crops can be successfully grown at such wide interspacing	Banerjee *et al.* (2009)
D. asper	Potato/tomato/ pea/ginger	Jharkhand	5m x 5m	Yield of all crops except pea was reduced. Growth of bamboos when intercropped with vegetables was better	Sinha (2010)
D. strictus	Blackgram/ greengram. sesame/cowpea	Odisha	10m x 10m; 12m x 10m	Blackgram and *D. strictus* was observed to be the best agroforestry system	NRCAF (2014)
D. strictus, *B. nutans*	Blackgram/ wheat	Jabalpur, Madhya Pradesh	6m x 4m; 6m x 5m	Favourable effect on yield of bamboo. Regular pruning resulted in increased number of harvestable culms and increased yield of crops	TFRI (2014)
B. bambos, *D. strictus*	Paddy, soybean/ mustard/ linseed	Raipur Chhattisgarh	8m x 3m; 8m x 6m	High feasibility to grow these crops with bamboo in the initial years	Naugraiya (2014)
B. bambos, *B. tulda*, *B. nutans*	Gomari/ turmeric	Assam	5m × 5m	Practically feasible and economically viable, while simultaneously improving the physico-chemical properties of soils	Gogoi (2011)

6.3.4 Wind breaks

For utility as low-lost fencing around farmlands or farm boundaries, planting *B. bambos*, a few meters from the periphery at close spacing (2-3m) can provide a real live thorny fence. With interlocked side branches, such fencing can deter stray cattle and provide extra income to the farmer by way of selling the sturdy culms and side branches. In many rural areas in Western Ghats, it is common to see the side branches of *B. bambos* being used as fencing material (Viswanath *et al.,* 2016). In Konkan belt of Maharashtra, it is common to see skilfully made live fencing of *D. stocksii* wherein the live clumps are managed laterally and the harvested culms tied together horizontally and vertically with the live clumps along farm periphery (Viswanath *et al.*, 2012). Monopodial bamboos like *Phyllostachys edulis* can also be trained for use as live fence (as in Gangtok, Sikkim) (Fig. 6.5). Closely planted bamboo culms (*D. strictus*) along with *Casuarina equisetifolia* has been successfully used as wind break to protect banana plantations in Coimbatore and also on east coast of Andhra Pradesh.

Fig. 6.5: Live fence on farm boundary using *Dendrocalamus stocksii* in Sindhudurg, Maharashtra (left) and *P. edulis* in Gangtok, Sikkim (right)

Another practice in the north-eastern India is the system of growing bamboo species like *B. tulda, B. bambos, B. balcooa,* and *D. hamiltonii,* on boundaries of paddy fields. This ensures soil and water conservation while meeting farmers' requirements of fodder, fuel and timber (Gogoi, 2015). This practice is also prominent in other regions of India like Bihar using the same species (Banik *et al.,* 2008)

6.3.5 Miscellaneous systems

In Assam, bamboos are often planted with trees like agarwood as a woody shade component in tea plantations and also mixed with other horticulture crops (Gogoi, 2015). A unique example of bamboo being grown with paddy combined with fish rearing has also been documented from Ziro valley of Arunachal Pradesh (Tangjang and Nair, 2015). An average farm in the region grows two woody perennials i.e. a variety of bamboo (*P. bambusoides*) and pine (*Pinus wallichiana*). Paddy is grown in two cropping cycles during summer and kharif season combined with fish rearing during the period in the flooded paddy fields. In recognition of this unique way of conserving ecology along with high productivity, UNESCO has added Ziro valley as a 'World Heritage Site' (Tangjang and Nair, 2015). Hence, recommending a bamboo species for cultivation in farmlands should consider the edapho-climatic considerations, species suitability, ease in management, multiple utility in farm, forward and backward linkages and the motive of farmer for taking up bamboo domestication or cultivation.

6.4 Bamboo Agroforestry Feasibility

In the Indian scenario, based on the property testing and assessment of inherent characteristics matching with end uses, the NMBA has selected 18 commercially important species, viz., *B. bambos, B. nutans, B. pallida, B. polymorpha, B. tulda, B. vulgaris, B. balcooa, D. brandisii, D. giganteus, D. hamiltonii, D. stocksii, D. strictus, D. asper, G. angustifolia, M. baccifera, O. travancorica, Schizostachyum dullooa* and *P. bambusoides.* However, matching them with their utility and suitable site conditions to ensure maximum productivity and outturn has not been done adequately, though this is an essential prerequisite (Table 6.3). *P. edulis, T. oliverii, B. wamin* and *B. multiplex* var. *striata* have now been identified to have potential in agroforestry and farm forestry (Viswanath *et al.*, 2016).

Table 6.3: Matching prominent bamboo species with site, utility and integration with agroforestry

S. No.	Suitable bamboo species	Most appropriate agro-climatic zone				Utility	Integration with agroforestry
		Humid	Sub-humid	Semi-arid	Sub-tropical		
1.	*B. bambos*	✓	✓	✓	✓	Construction, bioenergy plantations, on farm boundaries for bio-fencing, edible bamboo shoots, farm implements like ladders, etc., paper and pulp industry	Bio-fence, windbreak, homegardens, intercropping
2.	*B. nutans*	✓	✓	✓	✓	Bamboo furniture, edible bamboo shoots, bamboo furniture, agarbatti sticks small farm needs	Home gardens, windbreak, intercropping, block plantations
3.	*B. pallida*	✓	✓	✓		Basketry and handicrafts	Homegardens, block plantations
4.	*B. polymorpha*	✓	✓			Edible shoot, handicrafts, construction, pulping in paper industry.	Homegardens, block plantations
5.	*B. tulda*	✓	✓	✓	✓	Bamboo furniture, edible shoots, agarbatti sticks, small farm needs	Home gardens, intercropping, block plantations
6.	*B. vulgaris var. green*	✓	✓	✓		Bioenergy, edible bamboo shoots	Home gardens, intercropping, energy plantations
7.	*B. vugaris var. striata*	✓	✓	✓	✓	Ornamental value, used for landscaping purposes in gardens and parks	Homegardens
8.	*B. balcooa*	✓	✓	✓	✓	Construction, bioenergy plantations, farm boundaries, edible bamboo shoots, bamboo furniture	Homegardens, windbreak, intercropping, energy plantations
9.	*D. brandisii*	✓	✓		✓	edible bamboo shoots, sericulture industry for chandraki making, agarbatti sticks , small farm needs	Intercropping, home gardens, block plantations
10.	*D. giganteus*			✓	✓	Furniture, handicrafts, edible shoots.	Block plantations
11.	*D. hamiltonii*	✓	✓			Construction, basket making, edible shoots	Intercropping, grown along irrigation channels for fodder

12.	*D. stocksii*	✓	✓	✓	✓	Energy plantations, edible bamboo shoots, bamboo furniture	Bio-fence, home gardens, intercropping, block plantations
13.	*D. strictus*	✓	✓	✓		Construction, handicrafts and furniture industry, Bio-energy plantations, on farm boundaries, edible bamboo shoots	Homegardens, intercropping, rehabilitation of plantations, soil conservation
14.	*D. asper*	✓	✓		✓	Edible bamboo shoots, agarbatti sticks, small farm needs	Intercropping, home gardens, block plantations, bio-shield
15.	*G. angustifolia*	✓			✓	Construction, edible bamboo shoots, bio-drainage	Bio-shield in riverine areas, block plantations
16.	*M. baccifera*				✓	Construction, basket works, furniture, edible shoots, small farm needs	Plantations, afforestation
17.	*O. travancorica*				✓	Basketry, handicrafts	Bio-shield in riverine areas
	P. edulis					Bamboo furniture, bamboo boards, bamboo timber, edible shoots may be suited for N-E states like Sikkim and Meghalaya	Live fence in dry areas, soil conservation
18.	*T. oliverii*	✓	✓	✓	✓	Whole bamboo furniture, edible bamboo shoots, other small farm needs	Intercropping with crops, avenue, landscaping
19.	*B. wamin*	✓	✓	✓	✓	Ornamental value in home gardens and in landscaping	Live fence, avenue, landscaping
20.	*B. multiplex var. striata*	✓	✓	✓		Bio-fencing in farmlands, Ornamental value in landscaping	Live fence, avenue, landscaping

6.5 Hurdles in Bamboo-Based Agroforestry

As in the case of most agroforestry interventions, however promising bamboo may seem to be, to achieve success initial hiccups need to be addressed. These could be administrative, logistic as well as policy issues. Some salient drawbacks do remain to be addressed before bamboo can be fully integrated in the realm of cultivation. There is a dearth of quality planting material (QPM) of the desired bamboo species for farmers. Species like *D. stocksii*, which is very popular in central Western Ghats especially in the Konkan belt of Maharashtra and coastal districts of Karnataka, quality planting stock is scarce. A standard package of practice for cultivation of commercially important bamboo species is also unavailable. There is also a need to release clones/varieties with enhanced production potential to attract the farmers and motivate them to take up bamboo cultivation as viable alternative to horticultural crops such as mango, cashew or banana in humid tropics especially in coastal districts.

There is a dearth of quality planting material of the desired bamboo species. A standard package of practice for cultivation of commercially important bamboo species is also unavailable. There is also a need to release clones/varieties with enhanced production potential to attract the farmers and motivate them to take up bamboo cultivation as viable alternative to horticultural crops.

The acute paucity of quality planting stock can be addressed through innovative decentralized nursery schemes using vegetative macro-propagation techniques supported by Van Vigyan Kendras of ICFRE institutes, Krishi Vigyan Kendras of the agricultural universities, ICAR institutes as well as State Forest Departments. However, a more prudent and feasible solution to meet the huge demand of QPM could be to encourage commercial biotechnology labs or companies to take us mass propagation of various bamboo species through appropriate technology support and incentives to begin with. So far, the only success story in the bamboo sector seems to be Growmore Biotech Pvt. Ltd. (GBPL), Hosur, Tamil Nadu, which claims to produce 30,000 tissue culture plantlets of bamboo daily, mainly *B. balcooa*. GBPL claims to have sold nearly 60 lakh tissue culture bamboo plants till date in the country and abroad. More such ventures in the private and government sector is badly needed to meet the demand of QPM in bamboo. The current policies on transit and trade of harvested bamboo culms are hardly conducive for encouraging bamboo farming by farmers. A uniform policy across India covering all states on transit and trade will encourage farmers to cultivate the bamboo and industries to invest in processing units and value addition.

6.6 Best Practices through Research and Development

Based on R&D in bamboo-based agroforestry and farm forestry practices, certain recommendations may be made, which could qualify as best practices in current scenario

6.6.1 In homesteads

Land is always a constraint and within the limited space available in the home back yard, it is always advisable to plant a mid-size multi-utility bamboo species which can meet requirement of home nutrition, yield fodder for livestock, provide stakes for vegetable cultivation, non thorny as well as amenable to simple farm management practices by household members of the farm family. Species like *D. asper, D. stocksii, D. hamiltonii, D. strictus B. tulda, B. nutans, B. polymorpha* ideally fit the bill in the respective agro-climatic zones (see Table 6.1).

6.6.2 Block plantations in farm forestry

For establishing block plantations in farmlands or in marginal sites, the prerequisite is hat Bamboo has to be viewed as a horticultural crop. Adequate spacing not less than 4mx4m (depending on the species), pit size not less than one cubic meter (1cum), drip irrigation, fertilization, and intensive management practices. Timely harvesting of mature culms following maturity marking with colour codes have to be followed rigorously to get sustained yield. In large-scale plantation instead of digging pits it may be advisable to dig trenches of one m depth and filled with adequate farmyard manure/compost (not less than 25 kg/plant) mixed with good top soil. Block plantations also provide an excellent opportunity for in-situ vermicomposting due to copious litterfall (leaves, sheath and twigs) and may provide sufficient external input for sustaining soil productivity of the bamboo plantation.

Some of the bamboo species which have been successfully raised in block plantation include *D. stocksii* in Konkan belt of Maharashtra, *D. asper* in Indo-Gangetic plains and terai belt of Uttar Pradesh and Uttarakhand, *B. balcooa* in Terai belt, Western Ghats region and sub-humid regions in northern Karnataka, *B. tulda* in sub-humid regions of central India, *D. brandisii* in Coorg and Chickmaglur districts in Western Ghat region in Karnataka, *B. balcooa, B. tulda, B. pallida, B. nutans, B. polymorpha* in several north-eastern States. *T. oliverii* in farm forestry practices are common in many parts of Tripura.

Monopodial species like *Melocanna baccifera* have also been raised as monoculture species in Manipur and Mizoram in community forests. In higher elevations of Sikkim, Uttarakhand and Himachal Pradesh some hill bamboos like *D. falcatum, H. falconeri, T. spathiflorus* and *T. jaunsarensis* are seen over extensive areas, which are an important source of livelihood for dependent communities.

6.6.3 Wide-row intercropping with bamboo

The twin factors that influence the outcome of associated agricultural crops in agroforestry is light and moisture competition. Light is regulated by the extent of over-storey canopy of woody perennials and moisture completion occurs when the rooting pattern of the associated components tend to overlap. Inter-cropping in bamboo is generally not very successful after 3-4 years due to the spreading rooting behaviour of the fibrous root system. The root system of bamboo does not go beyond 1.5m depth and the fibrous roots of bamboo has the tendency to spread laterally and compete with the intercropped agricultural crops for moisture and nutrients through fine roots, however through appropriate spacing and selection of appropriate bamboo species having light feathery canopy and less branching habit, the problem can be mitigated to a large extent upto to a certain period.

Bamboo species such as *D. stocksii, D. strictus (erect variety), B. tulda, B. nutans* and *T. oliverii* can be used in intercropping by farmers in farmlands with low spreading pulse crops like horsegram, soybean, cowpea, green gram and mustard. Cereals like wheat and millets, food crops like ragi, finger millets, etc. can even be intercropped upto 6-7 years of bamboo cultivation in humid and sub-humid regions.

6.6.4 Planting on farm boundaries

Bamboo can be planted on farm boundaries as a biofence for physical protection of farm from intrusion by animals and as a barrier. A thorny bamboo species like B. bambos is ideally suited for this and has been deployed traditionally in many rural areas in Palakkad district of Kerala. The thorny side-branches are interlinked skilfully by trained workers and this type of fencing may last upto two years and is very cheap and effective. In many parts of India especially in West Bengal, Assam and Arunachal Pradesh, thin slivers made out of the bamboo culms of species like *B. nutans, B. tulda, B. polymorpha, B. balcooa* are interwoven and used in farm fences.

6.7 Future Strategies

The following steps may help in promoting cultivation of bamboo in agroforestry:

- Bamboo species should be prioritised for focused expansion in agroforestry on the basis of their utility, demand & supply.
- Nurseries of priority bamboo species with quality planting material should be established in the bamboo growing areas by the SFDs, forestry research organizations, industries, NGOs, communities and individuals, to ensure availability of quality planting stock.
- Bamboo planting may be encouraged on marginal lands with, as well as without, horticultural trees.
- The bamboo-based industries should be encouraged to adopt contract either by planting bamboo on farmlands under long term lease or providing inputs for bamboo plantation and buying produce through a buy-back arrangements with farmers.
- Tri-partite arrangements may be encouraged among the industry, farmer and a research organization to ensure the quality of planting stock and appropriate silvicultural and management practices, on the lines of pulpwood plantations in South India A quadripartite arrangement may be done adding a bank to the group, if financing is also required
- Minimum support price should be fixed by the Government for sale of bamboo at fair price
- Felling and transport of bamboo must be revised and made favourable to growers.
- Sale of bamboo products must be promoted through suitable measures, this would help sustain demand for bamboo produced in agroforestry.
- Bamboo cooperatives must be formed to help people collectively take up cultivation and sale of bamboo.
- Major bamboo agroforestry areas should be included in the cluster, and primary processing units may be set up close to such areas.
- Digitized information on bamboo nurseries, growers, buyers, market information etc., should be placed online.
- A network of bamboo growers may be created to allow exchange of information and facilitate collective action. A monthly bulletin or magazine may be of great help to the growers.
- Training programme for unemployed rural youth must be conducted under Pradhan Mantri Kaushal Vikas Yojana in leading forestry institutions. The training should cover not only planting of bamboo as well as management of bamboo plantations.

6.8 Summary

In general bamboos with their multiple uses, fast growth, erect culms and shallow fibrous root system are suitable for agroforestry, plantation forestry and farm forestry programmes. However despite the wide distribution of bamboo, its spread in agroforestry is mainly limited to farm boundaries, homesteads and marginal areas. National Mission on Bamboo Application, Govt. of India has identified 19 species as industrially important. However, it is necessary to prioritise a much smaller number of species, based on growth rate and industrial utility, for focused research and development. Managing the species and matching appropriate bamboo species with site conditions could be the key to achieve the desired objectives in agroforestry. Addressing the current drawbacks in availability of quality planting stock as well as trade and transit issues can also help in popularizing bamboo agroforestry among farmers in India.

CHAPTER - 7

PROCESSING AND VALUE-ADDITION

7.1 Introduction

Bamboo is one of the most versatile and economically important raw materials for a variety of products. Its traditional uses include fuel, construction, agricultural tools, furniture, containers, medicine, food, shelter, hunting and fishing gear and other items for household purposes. It needs to be leveraged towards the alleviation of rural poverty and environment rejuvenation. It is possible to develop and strengthen the prevalent craft traditions and ensure a reasonable economic benefit to the people, and at the same time maintain a cultural continuity in the rural tribal way of life (Anon., 1994; Muraleedharan *et al*., 2001; Muraleedharan and Anitha, 2007, Jayasankar, 1996; Anitha, 2008, 2012;). It is an excellent material for house construction in earthquake prone areas.

The bamboo industry, with immense economic potential in a labour-surplus Indian economy, plays an important role in both traditional and non-traditional sectors. Artisans make bamboo products for their sustenance and they are endowed only with traditional skills, tools and work experience. Their bamboo-based productive activities mainly involve the four stages, viz., procurement, processing, production and marketing. The raw material requirement of the bamboo dependents is mainly sourced from natural areas/forest depots, private depots, local market and home gardens. There is no technological innovation and mechanization involved in processing and production. The sector follows basically labour intensive methods and the role of capital is near-zero. Production is a small scale household based activity with traditional tools, and there is very little scope for product diversification and value addition.

7.2 Pre-Harvest Considerations

The natural durability of bamboo depends on species, climatic conditions and type of use. The average life of untreated bamboos is less than two years. Bamboos thus fall in class-III (non-durable category) with little variation in durability among different species. Variation in durability has also been observed across the length of the culm and the thickness of the wall. The lower portion of the culm is considered more durable, while the inner part of the wall deteriorates faster than the outer harder portion. This is probably related to the anatomical and chemical nature of the woody cells.

For lowering the sugar content to protect the bamboo against the borers, typical traditional methods are followed, which include:

1. Felling during low sugar content season: Felling of bamboo is done during season of low sugar content, the period of this varies with locality. In India, for example, it is higher in spring than in winter. It is therefore advisable to harvest bamboo during the winter months.
2. Felling of mature bamboo: Sugar content in culm varies with age. The content is lowest during the first year. However, the usefulness of very young bamboos is limited due to their low strength and yield.

7.3 Post-Harvest Treatment

Bamboos are subjected to post-harvest damage by fungi and insects. Guha *et al.* (1975) reported the loss of 20 to 25% due to microbial decay during one year of storage. Harsh and Kapse (1999) have reported a loss of about 26.5% in weight in open storage during one year due to Basidiomycetes decay fungi. It is therefore, obvious that enormous financial and material losses occur due to post-harvest fungal decay. Besides, fungal decay of bamboo, it results in about 20% loss in yield (Bakshi *et al.*, 1960), about 50% loss in strength of the pulp, increase in consumption of bleaching chemicals, bulking problem in digesters, loss of materials during clipping and screening and overall loss of the quality of the pulp (Bakshi *et al.*, 1968).

Though spraying with chemical mixture of boric acid and borax mixture is effective in controlling the decay in stored bamboos, its effectiveness is second only to the treatment with Trichoderma. Re-isolation of Trichoderma sp. from the treated bamboo sticks confirms that the biocontrol agent establishes in bamboo and continues to work against decay fungi. The comparison indicates superiority of Trichoderma treatment over chemical treatment. Moreover, the chemicals have short-term effect against the decay fungi particularly during long period of storage (Harsh, 2008).

7.3.1 Post-harvesting transpiration of culm

Sugar content in bamboo can also be reduced by keeping culms upright or leaning them against trees for a few days, with the branches and leaves intact. Parenchyma cells in plants continue to live for some time, even after felling. During this period, the stored food materials are utilized and thus the sugar content of the bamboo is lowered.

7.3.2 Protection outside storage

FRI and other organisations have carried out laboratory studies on outside storage of bamboo with and without preservative treatment. Sodium pentachlorophenate (NaPCP) and a mixture of boric acid-borax were found quite effective in controlling biological decay. Substantial protection in quality and quantity of bamboo was achieved by prophylactic treatment.

7.3.3 Water soaking

The traditional and most simple method involves immersion of felled culms in water. This method may be effective only in preventing damage from Bostrychid beetles. It is suitable only for those bamboos which have a low starch content (Sulthoni, 1990), require a long time for lowering of sugar content, and culms treated in this way tend to blacken. The soaking method is commonly used in many Asian and African countries and consists of submerging freshly cut culms for 4-12 weeks in stagnant or running water, or mud (Sulthoni, 1987). Generally, stones are placed on top of the bamboo to keep it submerged during the soaking period.

7.3.4 Smoking

Traditionally, bamboo culms are placed above fire-places inside the house so that the smoke and heat rise up and dry and blacken the culms. It is possible that the process produces some toxic agents that provide a degree of protection. Alternatively, the heat generated by the fire could possibly destroy or reduce the starch content of the parenchyma cells by pyrolysis.

7.3.5 Whitewashing

Bamboo culms and bamboo mats for house construction are often painted with slaked lime. This is carried out mainly to enhance the appearance, but there is also an expectation that the process will prolong the life of the bamboo structure by preventing moisture entering the culms. It is possible that water or moisture absorption is delayed or in some cases prevented which will provide a higher resistance to fungal attack.

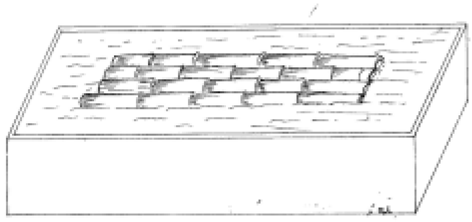
7.4 Chemical Methods of Treatment

FRI and other research organisations have worked on different species for development of preservatives and treatment methods. Bamboos can be treated in dry as well as in green condition; the methods are entirely different for both.

7.4.1 Treatment of green culms

The following methods are commonly used for treating green bamboo:

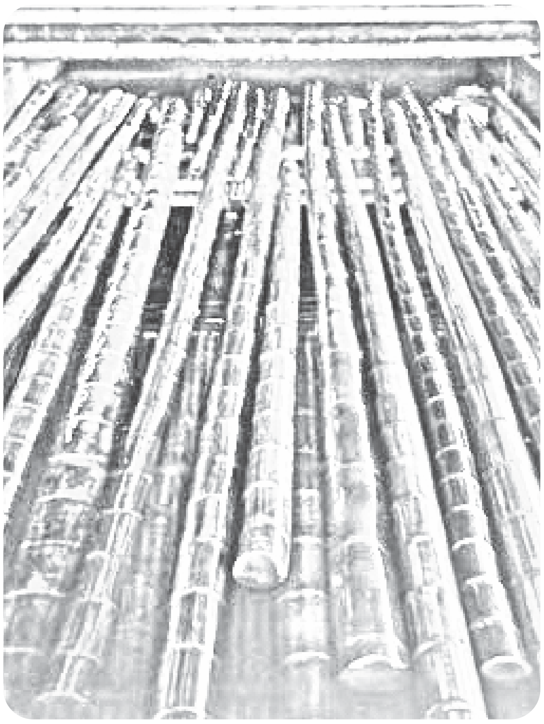
a) Sap-displacement or Wick Process
b) Boucherie method
c) Modified Boucherie method
d) VAC-FRI (Application of initial small vacuum before treatment)



7.4.2 Treatment of dry culms

Dry solid bamboo poses problems in the treatment due to the presence of silica and wax on the upper skin. Methods of treatment include:

a) Soaking treatments
b) Hot and cold process
c) Pressure treatment



7.4.3 Chemicals (preservatives) commonly used for protection

There are three categories of chemicals used for preservative treatments.

a) Copper-chrome-arsenic (CCA), ammonical copper arsenite (ACA) and copper-chrome-boron (CCB) are commonly used for long-term protection of bamboo.
b) Borax: boric acid mixture is used for interior application.
c) Borax: boric acid: sodium pentachlorophenate mixture (NaPCP) is recommended for prophylactic treatments for short durations.

Bamboo can be treated by all three types of preservatives. Most of the chemicals which are used for bamboo protection are applied at 4-6% concentration.

7.4.4 Service life after treatment

The performance of treated bamboo was evaluated in ground contact under graveyard tests by FRI. The ACA, CCB, CCA and creosote: fuel oil treated bamboo had remarkably enhanced service life. Mud reinforced treated bamboo exhibited more than 53 years of life. FRI is constructing low cost huts which are made of treated bamboo. The bamboo installed is treated with ZiBOC, a newly developed eco-friendly wood preservative. Demonstration structures establish that post-harvest treatment of bamboo enhances life of structures several folds as compared to untreated ones.

7.4.5 Fire retardant treatment

Fire presents a potential hazard in any form of construction, but the risk is especially high in bamboo buildings. The combination of bamboo and matting coupled with the tendency of the internodes to burst causes rapid fire spread. The danger is increased when the joint lashings are destroyed which can cause catastrophic collapse of the building. It is, however, possible to treat bamboo with a combination of preservative and fire retardant chemicals. The process is normally carried out by pressure treatment. The cost of fire retardant treatment is generally high and therefore, this treatment is seldom applied. Finding a suitable cost effective treatment, that can provide combined protection against biodegradation and fire, is future area of research. Boron-based retardants offer a possible solution, with the added advantage of being relatively safe to use.

7.5 Drying

FRI and other research organisations have worked on different species for development of preservatives and treatment methods. Bamboos can be treated in dry as well as in green condition; the methods are entirely different for both.

7.5.1 Kiln drying

At the present level of drying technology, kiln drying of round bamboo is not feasible. Even mild drying conditions can increase the incidence of cracking and collapse. Split bamboo can, however, be kiln dried. The cost of kiln drying / material cost (bamboo) may also be a limiting factor.

7.5.2 Air drying

Air drying takes 6-12 weeks, depending on the initial moisture content and wall thickness. Collapse can be a major problem in some species, owing to excessive and non-uniform shrinkage of the culm. However, problems are mostly seen in drying of immature culms. It is recommended that only mature culms are used. Air drying of split bamboo does not pose any problems, even in direct sunlight.

Chemical seasoning of *D. giganteus* has been tried earlier using poly ethylene glycol-600 (PEG). Urea and common salt have also been tried and are much cheaper as compared to PEG. *B. nutans*, *D. membranaceus* and *D. giganteus* in round form can be seasoned without drying degrades like cracking and splitting after giving it an anti-shrink treatment in green freshly felled condition. However such treatment may be suitable to mostly handicraft items.

7.6 Processing

A bamboo-based product unit provides income generation and skills development to those that it employs. Weaving can be done on site or at home in spare time or full time. Increasing the use of local bamboo resources also encourages their sustainable management and benefits the bamboo cultivators. Majority of the bamboo-based industries are grouped as cottage and small-scale enterprise.

7.6.1 Processing chain

True benefits accrue to manufacturers of industrial products out of bamboo only when appropriate techniques of processing are utilised in the production process. For this, it is the processing which adds longevity, preservation and extra strength, as well as finishing necessary for a high-value product (https://www.scribd.com/document/340527377/Group12-IM23B-Bamboo-Supply-Chain-pdf). Bamboo being a large plant with -immense diversity whose every part can be utilized productively, the bamboo processing chain is a complicated involving multiple stages. Studies on mapping the chain and studying methods of further optimising and enhancing the efficacy of processing have been conducted, both for the general bamboo product (Belcher, 1995) and for individual industries (Janssen, 2000). A detailed description of the processing chain for bamboo products is available (Gnanaharan and Mosteiro, 1997).

7.6.2 Primary and secondary processing

The primary processing and strip formation of bamboo utilisation includes harvesting, storage, transportation, preservation and seasoning. The secondary processing line includes fabrication of value-added products. The aspects of grading (strength / feature / colour / exterior / interior based) and quality control are none the less important including the functional tests on products such as furniture, joinery and structures. Making of value-added products follows bamboo processing.

7.6.2.1 Primary processing

After preparation, the culm is ready for primary processing. For use in woven products, the culm has to be split into strips, and then the strips further processed to get splits and slivers. For splitting into strips, simple techniques have been developed in different countries. Two pairs of slits are made at right angle to each other at the top end of the culm, and the slits are held open with wedges until the culm is placed in position on the cross. Then the culm is pushed and pulled by hand until it splits. A steel wedge can be used for splitting quartered culms. Depending on the thickness of the wall, different contrivances are used. For fairly thick culms, two cuts perpendicular to each other are made at one end of the culm, and a plus-shaped contrivance is placed on the cuts made and pushed down gradually by hammering lightly with the back of a knife.

For thin-walled culms, a small rod or a cross-shaped rod is used. A radial knife can also be used, either by hand or in a machine. Depending on the diameter of the culm and the width of the required strips, knives with different numbers of blades are used. The manual use of a radial knife in Colombia is described by Hidalgo (1992). A knife or a machete can also be used for splitting. It should have a broad blade made of hardened steel (http://teca.fao.org/technology/local-tools-and-equipment), and should be heavy and sharp enough to split the bamboo with one stroke.

The strips are further divided into splits and the splits into slivers. The splits may be made radially or tangentially. While making tangential divisions, any pithy, inner portion is usually discarded. A long-handled knife with the blade bevelled on one side is suggested for these operations (McClure, 1953). The artisans in Assam use a dao or broad-bladed knife, while the artisans of Manipur use flat-bladed knives of different sizes known locally known as sangai (small blade) and thangjou (wide blade) (http://teca.fao.org/read/3877).

To make the thickness of the splits uniform, different methods are employed. In one method, a thick cloth is spread on the thigh and the split is placed over it. Then the split is pulled while pressure is applied on it with the edge of a shaving knife. In another method, the split is kept over a wooden block and pulled over a knife. Another method to size the width is to use a pair of knives. The knives are fixed on to a wooden block, with the gap between them set according to the width of the split required. The oversized split is pushed through with the left hand while the other end is pulled by the right hand. To give a finishing touch to the splits, different chamfering knives are used. Alternatively, a knife plate fixed to a wooden block may be used for the purpose.

7.6.2.1.1 Primary processing for mat-based products

Bamboo mat is the primary raw material for processing into any bamboo mat based panel product, and proper understanding of the process involved in making bamboo mats is essential for procurement of right type and quality of mats as also their safe transport and proper storage.

For making mats, bamboo is split into thin slivers, thickness of about 1–1.5 mm, and width 1.5 to 2 cm through the following basic steps:

- Harvesting bamboo culms and removing the tips and branches
- Cross-cutting culms into sections of a standard length
- Longitudinal splitting of culms into splits
- Removing the green epidermal layer and knots to produce slabs
- Splitting the slabs into slivers

  Preservative treatment

Cross cutting machine

Splitting machine

Knot removing and slab-making machine

Sliver making machine

Fig. 7.1: Bamboo primary processing unit at IPIRTI, Bengaluru

These processes have been done by hand for many generations. For making quality bamboo mat for further processing into industrial products one of the important concerns is the uniform thickness of slivers and the thickness at the knot portions. To get good quality slivers, technology has been developed at IPIRTI. The mechanical unit for making sliver permits the efficient production of large quantity of splits for large-scale supply, generally to industrial processing plants. Such machineries are available now available at other research organisation like FRI (Tripathi, 2015) Dehradun and units across the country.

7.6.2.1.2 Processing splits into rounds and chopsticks

In India, manually operated equipment is available to make bamboo rounds for the manufacture of incense sticks. Mechanized equipment is also available for making chopsticks. For making thin ribs out of splits, a simple gadget a strong steel plate with holes of different diameter is used. The split is pulled through a larger hole first and later passed through smaller holes. This makes the rib round, even and attractive.

7.6.2.1.3 Straightening whole culm

For straightening the bamboo, different contrivances are used depending on culm size. For small-diameter culms, simple wooden blocks with hole or notch are used. For large-sized culms, metal contrivances should be fixed firmly (teca.fao.org/es/read/3877).

7.6.2.1.4 Bending round culm

Bending a green round culm is much easier than bending a dried one. It is relatively easy to bend an immature culm, but it will revert to its original state within a very short time. For bending culms which are slender and thick-walled, heat should be applied at the point where it is to be bent. The heat should be just sufficient for bending. When the required bend is completed, the heated portion should be kept immersed in water till the water temperature reverts to ambient.

In a local technique employed in Assam and other parts of India, for making umbrella handles, the culm is filled with sand and the ends are sealed with cow dung. This prevents the stick from cracking while bending under heat. Normally a charcoal fire is employed to heat the culm. A spirit lamp can also be used for heating, especially if the culm is to be used in an art ware.

7.6.2.1.5 Bending strips

Bamboo strips are bent at the internodal portion. At the place of bending a small portion is hollowed out and heat is applied there. An electrically-heated bar will speed up the bending and allow the heating time to be regulated. After bending, the heated portion is cooled by keeping it immersed in water (Kallapur, 1989).

7.6.2.1.6 Flattening

The craft workers in the north-eastern states of India make containers using internodal portions of whole or half-split culms. Heat is used to flatten a bamboo culm into a sheet without letting it develop any cracks. Ranjan *et al.* (1986) described the process: a section of the internode (about 900 mm in length) of a freshly cut culm is peeled to a wall thickness of 1-1.5 mm and split along its length. A toxic resin, kharu obtained from katong tree, is mixed with water and applied on both surfaces. According to the Khoibu artisans of Manipur, this resin prevents the culm from developing cracks while being heated (www.teca.fao.org/pt-br/read/3877). Applying heat evenly along the length makes it pliable and it opens out. A stick is used to press the culm flat on the ground. While the sheet is still hot, it is bent so that the inside surfaces of the internode forms the outside surface of the bent article. The joint is held in a split bamboo clamp, a very simple device made from a length of a thick culm partially split in half along its length. The overlapped ends of the sheet are held together by two rows of stitches made with cotton thread.

7.6.2.1.7 Slicing

Grewal *et al*. (1994) describe a simple hand-operated slicer that can slice bamboo splits into 0.2 mm thick slivers used in manufacturing fine basketry and novelty items. Slotting bamboo has been used in the construction of screens to remove fine sand and silt in wells in India and Bangladesh.

7.6.2.2 Secondary processing
7.6.2.2.1 Bleaching

Coloration due to the presence of gums, resins or oily substances mars the appearance. Bleaching is resorted to in these circumstances. The following indigenous methods are taken from Ranjan *et al.* (1986). The artisans of Manipur collect the bark of shai-kui tree, pound it and then boil it in water to release the dye. Bamboo splits are put in this boiling solution for a short while before taking them out for drying and smoking over a fireplace. This process produces a deep brown-black colour. The

Khiamngan Nagas use the leaves of ham tree. Fresh leaves are pounded and mixed with water. Bamboo splits are put into this and boiled for two to four days continuously, till both the leaves and the bamboo splits turn a deep yellow. When the required colour is obtained, the splits are removed and dried under shade.

The following method is used to dye the yellow splits red: bark of lungpai tree, after scraping off the outer layer, is pounded to a very fine powder. Water is added to cover the bark powder and allowed to stand for two to four days. The yellow splits of bamboo are boiled in this mixture till the splits acquire the desired red colour. Besides vegetable dyes, commercial dyes are also used for dyeing bamboo splits. Standard dyeing procedures have been developed for using these dyes. However, it is good to keep the following points in mind before drying. It is better to bleach the bamboo splits before dyeing as bleached splits will take the colour uniformly (http://teca.fao.org/technology/local-tools-and-equipment-technologies-processing-bamboo-and-rattan-asia). The outer skin of bamboo splits should be completely peeled. To ensure colour fastness, the dyed bamboo split should be washed with a warm acetic acid solution (Kallapur, 1989). Finished bamboo articles can also be dyed using commercial dyes.

7.7.2.2.2 Finishing

Different finishing methods are used depending on the type of end-use and the specific product. These include:

7.7.2.2.3 Smoking

The artisans of the Khiamngan Naga tribe use outer splits for warp and scraped-off hard outer skin for weft in woven products. The finished product is subjected to prolonged smoking over a fireplace (Ranjan *et al*., 1986).

7.7.2.2.4 Lacquering

Bone ash is used because of its absorbent quality. After the mixture is applied, the article is rubbed vigorously with sandstone to make it smooth. Presently, artisans use ready-made synthetic lacquer available in the market. Lacquering is done either by spraying or by brushing. To get a special finish, cashew lacquer (1 part cashew nut oil in 5 parts of turpentine thinner) is used (Anon., 1983). Modern industrial lacquers are known for their brilliant and durable coatings. They contain a soluble cellulose compound, resins and plasticizers. These ingredients are dissolved in a mixture of volatile solvents and diluents (non-solvents). The plasticizers incorporated impart flexibility, while the resins give lustre, adhesion, durability and water resistance. In coloured lacquers, besides pigments, stabilizers are also added to ensure colour fastness (Kallapur, 1989). Articles like screens, fans, lamp shades, etc. are finished with varnish readily available in the market. Polyurethane varnish is currently popular because of its durability and scratch resistance. Depending on the product, varnish can be applied by brushing or spraying.

In one method, juice obtained from neem leaves by crushing and grinding is applied on the bamboo articles. This is believed to keep away borers. In the second method, cotton cloth cuttings are charred, linseed oil (or oil of *Semicarpus anacardium*) is slowly added to it and the mixture is ground in a pestle and mortar. The sticky paste thus obtained is applied to utility articles working into all the crevices. This is believed to increase the service life of the articles.

7.6.3 Challenges in the transformation system

An account of the problems of bamboo transformation system is being presented below based on detailed reviewe by Baksy (2013).

Poor quality supplies: Bamboo reaches the manufacturer through aggregator middlemen who collect bamboo harvested by cultivators. Collectors generally do not care about quality bamboo. Grading and sorting is done to some extent by middlemen who supply bamboo to manufacturers.

Low volumes of supplies: About 44% of the total bamboo cultivated is utilised in the paper and pulp industry and in scaffolding for construction without much value addition. Other users face shortage of bamboo, especially bamboo of certain grade or species.

Lack of trained labour: Traditional skills employed by the artisans do not allow industry-level production speed, scale and quality.

and practices but it makes the use of bamboo limited to rural areas because the traditional approach, while often adequate for service conditions, is unable to address ultimate limit states and a limit states approach requires specialized knowledge and engineering which may not be readily available. Thus the new standard still has some scope of improvement to realise the full potential of bamboo as a sustainable and utilized building material on an international scale. Harries *et al.* (2012) further proposed a standardized test methods on bamboo suitable for the field by characterizing the longitudinal splitting behaviour of full-culm bamboo.

7.7.2 Structural application by FRI and IIT, Delhi

FRI and IIT Delhi has done work on structural testing and application of bamboo. These works mainly comprise design and analysis of bamboo structures and are not related with testing and characterization of bamboo species based on bending behaviour of full bamboo culm. No book or code of practice is available for design of bamboo structures on scientific lines and hence Steel Code (IS: 800, 1984) has been adapted wherever necessary by the IIT, Delhi for designing various bamboo structures. Most of the design, analysis and construction are carried out on the species *D. strictus* while structures were designed on the basis of *D. giganteus* (Ghavami, 2007). Bending data are neither evaluated nor taken care of. However, new BIS standard (IS: 6874: 2008) and International standard (ISO: 2004) mainly emphasize on bending test on larger sized of bamboo.

7.7.3 National Building Code 2016

The National Building Code of India (NBC), a comprehensive building Code, is a national instrument providing guidelines for regulating the building construction activities across the country. NBC (2016) has added some traditional design issues with bamboo construction. It still has scope for improvement by adding basic strength data of various structural members that match with the actual field conditions. Introducing novel design of structural joints and other systems with support of technical data may further enhance the acceptability of bamboo among the builders and architects.

7.8 Composites

A composite generally signifies two or more materials that are combined on a macroscopic scale to form a useful material. Several types of wood composites are available. The basic wood elements used in composites include logs, lumber, thin lumber and veneer, large flakes, chips, small flakes, excelsior, strands, particle, fibre bundles, paper fibre, wood flour and cellulose.

Bamboo has developed as a specially valuable and superior alternative to wood composite manufactured, such as for pulp and paper, stripboards, matboards, veneer, plywood, particleboard, fibreboard, inorganic-bonded board (i.e., cement), wood plastic composite (WPC). Moreover, several researches have used it as raw material for structural composites such as oriented strand board (OSB), glue laminated timber (GLT), parallel strip lumber (PSL) and oriented strand lumber (OSL). Nowadays, there are many kinds of bamboo composites which are produced and traded in the world. However, there are several differences between bamboo and wood, *e.g.,* macroscopic and microscopic characteristics, chemical composition, physical and mechanical properties which successfully compete with wood and other raw materials in the future.

In India, research efforts to make building boards from bamboo were initiated in the mid-1950s at the Forest Research Institute, Dehradun, and several processes were evolved till early sixties (Narayanamurthi and Bist, 1963). At present more than 20 different types of panels are produced in Asia. However, industrial production of bamboo mat board (BMB) in the country started in the mid-1980s with the development of technology for making BMB from the reed bamboos, *O. travancorica* and *O. rheedi*, by IPIRTI. Significant Research and Development (R&D) efforts have already been made at the Indian Plywood Industry Research and Training Institute (IPIRTI), Bengaluru which led to the development of several innovative bamboo composites products which can be broadly categorized into: bamboo strip based products, bamboo lumber and bamboo particle board.

7.8.1 Bamboo mat-based products

Range of bamboo mat based products are developed mainly bamboo mat board (BMB), bamboo mat veneer composite (BMVC), bamboo mat corrugated sheet (BMCS), bamboo mat ridge cap (BMRC), bamboo mat moulded skin board (BMMSB) and other bamboo mat based products. Such value added bamboo products can contribute significantly in reducing energy consumption and carbon footprints by cutting down on non-renewable building materials, *viz.* steel, concrete, aluminium, etc.. (Mohanty *et al.,* 2017).

7.8.2 Bamboo Strip Based Products

Bamboo strip based products are so designed to behave like solid wood in properties and applications. The products have applications as flooring material as well as in furniture manufacture. As of now bamboo laminates are being manufactured in China from monopodial bamboo *Phyllostachys pubescens* and have great market demand in Europe and America. IPIRTI has developed several strip based bamboo products such as bamboo vertical laminate ; bamboo horizontal laminate; bamboo floor tiles and bamboo flattened board (Mohanty *et al.,* 2017).

7.8.3 Bamboo lumber based products

These are third generation bamboo products with a potential to replace conventional solid wood such as teak flooring (Mohanty et al., 2017).

7.8.4 Bamboo particle board

Bamboo is a suitable raw material for making particle board due to its long fiber, wider availability and fast growing nature. Use of bamboo for making particle board will widen raw material base as well as use of bamboo would bring regular source of earning to bamboo growers. Several cost effective, people and eco-friendly technology for manufacture of several bamboo-based products are now available.

The bamboo panels are widely used in modern construction as structural elements or as forms for concrete mouldings. They are also used for flooring, roofing, partitions, doors and window frames. Various types of bamboo veneers, panels and boards can be broadly classified as veneer-based boards, strip boards, mat boards, fibreboards, particle boards, medium density boards, combinations of these, and combinations of these with wood and other ligno-cellulose materials and inorganic substances. Composites of bamboo and jute are used to make panels.

7.8.5 Reconstituted wood

Reconstituted products involve steps of progressive reduction in size of raw material followed by alignment and bonding. A sequence has been evolved in which raw material is reduced partially to a conditions, as far as practicable, in which the elements remain interlocked and are in their highly aligned state and from which with the help of binder, raw material can be reconsolidated to a desirable size. Reconstituted wood possesses directional strength properties too.

Physical and mechanical properties of the reconstituted wood developed from bamboo (*D. strictus, B. polymorpaha, D. giganteus and B. balcooa*) were compared with teak. In most properties products is comparable or better than teak wood (Singh, 1995-96, Shukla *et al.*, 1988, Khali and Singh, 2014-15).

Reconstituted wood developed from bamboo offers a potential for the substitution of solid wood for structural uses. It may be used for furniture, doors and window frames, beams and many loads bearing structure.

7.8.6 Mat board

Bamboo mat board (BMB) is essentially a layered composite comprising several layers of woven mats having excellent internal bond strength, and are resistant to decay, insects and termite attack. They have physical and mechanical properties similar to water proof plywood and are fire resistant. Their mechanical properties depend upon the material used for making mats, *i.e.*, bamboo slivers, the weaving pattern and the adhesive used for bonding. Ten species, *viz., D. strictus, D. hamiltonii, D. brandisii, M. baccifera, O. travancorica, B. nutans, B. bambos, B. balcooa, B. tulda* and *Schizostachyam dullooa* have been studied for this purpose.

7.8.7 Veneer composites

In bamboo mat veneer composites (BMVC), wood veneers are placed between the layers of bamboo mats. The properties of BMVC depend upon the mechanical properties of wood veneers, in addition to the properties of the bamboo mats and the adhesives used in bonding. The properties are comparable to that of structural plywood. Hence, for all practical purposes BMVC can be used in a way similar to plywood for structural applications. BMVC will be economical in higher thickness as compared to BMB.

7.8.8 Mat moulded products

Considering the flexibility of bamboo mats due to "herring-bone" weaving pattern, a process was developed to produce moulded products like trays in various forms like rectangular, round, etc. They are called bamboo mat moulded products (BMMP) moulded products were found to be highly durable and leak proof, which can be conveniently used for various applications like those based on metals, plastics, etc.

7.8.9 Mat corrugated sheet

Of late priority is being given, and rightly so to 'green' building materials, based on renewable resources. Bamboo mat corrugated sheet (BMCS) constitutes an excellent alternative to corrugated metal, plastic or asbestos roofing sheets. Roofing materials such as asbestos cement corrugated sheeting (ACCS), corrugated fibre reinforced plastics (CFRPs have been produced for use similar to corrugated aluminium sheeting (CAS), corrugated galvanized iron sheeting (CGIS). These bamboo-based materials are being subjected to scientific scrutiny on several counts, including their impact on workers health and environment, the energy requirement for their manufacture, and sustainable supply of raw materials.

7.8.10 Mat ridge cap

Bamboo mat ridge cap (BMRC) is an integral part of BMCS and is used to build house/structure where as BMCS is being used as roofing material.

7.8.11 Mat moulded skin boards

Presently high density or medium density hardboards are being imported by the country for making hollow core flush doors. Bamboo mat moulded skin board (BMMSB) is an alternative material and is superior in quality to skin board imported from abroad and help in import substitution. The production of doors using imported skin board is about 12 lakh boards per year. Doors with HB/MDF skin board can be replaced with bamboo mat moulded skin board overlaid with PVC membrane foil having wood texture, grain and colour. A cost-effective technology for making door skin using bamboo mat has been developed at IPIRTI.

7.8.12 Bamboo wood

Bamboo strips are arranged in one and the same direction during assembling, and then pressed bi-directionally. The strips are bleached or carbonized before pressing. The products are multi-layered and formed in large dimension. The surface of laminated bamboo board is fine-grained. They can be used for furniture making and inner decoration like laminated veneer wood or high-grade wood. This is a new type of bamboo-wood flooring with outward appearance of bamboo and properties of wood. It is composed of thin bamboo pieces as front and rear surface layers, wood boards 8~15 mm in thickness as inner layers. IPIRTI has developed bamboo laminates of both horizontal and vertical type.

7.8.13 Strip board

Laboratory scale technology has been developed to make bamboo strip boards from bamboo strips. The developmental work was limited to laboratory scale of size 45cm x 45cm. The panel developed possesses high strength, stiffness and rigidity. It is characterized by resistance to deformation, abrasion and weathering. Its bending strength properties are superior to wood panel and, therefore, application potential, particularly as platform boards, vehicle platforms, transport floorings, etc., is very high.

The use of bamboo in construction is still an emerging field, as is the use of engineered bamboo products. Several factors need to be addressed for engineered bamboo products to be used in construction. Engineering quantification of mechanical properties will determine the potential structural applications. There is also a need for further testing based on standardised methods, such as existing timber testing methods. With a consensus on the test methods utilised to characterise bamboo materials, a knowledge base will be formed to develop structural products, as well as the codification necessary to utilise these materials in the mainstream market. In addition to the technical aspects of engineered bamboo, the environmental impacts associated with the production of the products need to be explored. Research on the various inputs and processes used to develop these novel products will provide a foundation on which to increase efficiency and reduce the associated impacts.

Fig. 7.2: Products of Bamboo primary processing unit at IPIRTI, Bengaluru

7.8.14 Fibre reinforced thermoplastics

This product segment includes bamboo reinforced PP (polypropylene) and bamboo mat-acrylic based products for utility and automobile products. Bamboo waste and dust of appropriate mesh size along with coupling agent provide reinforcement to the PP to enable required PP/raw material characteristic for manufacturing different utility and automobile products. It improves viability of the product and adds value to the bamboo and bamboo processing waste.

Bamboo mat-acrylic moulded product provides an opportunity to link mat weaving communities with industrial units. A bamboo mat acrylic product manufacturing unit is operational at Kudal (Maharashtra) and first bamboo fibre reinforced thermoplastic granule manufacturing unit is coming up at Mangalore, with technical and financial support of the NMBA. Cost of bamboo mat acrylic product manufacturing unit is Rs. 90 lakhs, with production capacity of 7.5 lakh square feet per annum, with a payback period of two years. Cost of setting up a project for manufacture of bamboo fibre reinforced thermoplastics is around rupees 6 crore (for a capacity of 15000 tonne per annum) with IRR of 27 per cent. Both these products have immense potential for value addition of bamboo, as well as potential for limited substitution of thermoplastics with biodegradable bamboo material.

Machinery

The bamboo-based panel products require preliminary processing converting hollow and round bamboo into the slivers/strips/fibres which are the basic raw material for mats or laminated products. A cross-cutting machine, splitting machine, knot removing and slab-making machine, and slivering machine are the basic requirement for bamboo mat formation. There are a number of bamboo primary processing machineries manufacturing units within the country with a major hub in Dewas in Madhya Pradesh. The cost of the machines varies significantly depending on the quality of the machines and scale of operations.

The woven bamboo mat based products like BMB, BMBC, BMRC, etc. requires primarily resin kettle, resin applicator, drying chamber/band dryer, steam boiler, hot press, scissor lift, measuring instruments, blowers, compressors, sprayer, conveyor, etc. All these machines are indigenously available. The capital investment (excluding building and land) is estimated to be about Rs. 1.40 crore for bamboo mat preparation with a capacity of making 400 sheets per shift and about Rs. 3.50-4.00 crore for bamboo mat board production and other related products based on such boards. However, the existing plywood manufacturing units can also be upgraded for BMB production with about Rs. 50-60 lakh investment. The production costs of various bamboo mat based products have been worked out by IPIRTI and the same are given in the Table 7.2.

Table 7.1: Production cost estimates of various bamboo-based composites products

Product and capacity	Production cost and size
Bamboo mat board (320 boards per shift)	Rs. 567.84 per board (2440 mm × 1220mm × 4 mm)
Bamboo mat corrugated sheet (225 sheet/shift)	Rs. 586 per sheet (2440 mm × 1050 mm × 3.5-3.7 mm)
Bamboo mat ridge cap (192 sheets per shift)	Rs. 343 per sheet (430 mm × 1050 mm × 3.5 – 4.0 mm)
Bamboo mat moulded skins for doors (100 doors/day)	Rs. 120 per sheet (1800 m × 920 m × 3.7 mm)
Bamboo mat trays (100 trays per shift)	Rs. 60 per tray (30 cm × 22.5 cm or 40 cm × 30 cm)
Bamboo mat veneer board (225 boards /shift)	Rs. 1689 per board (2440 mm ×1220 mm × 12 mm)
Laminated bamboo board (270 boards/day)	Rs. 290 per slab (1220 mm × 720 mm × 19 mm)

(Source: IPIRTI)

Few industries have also been established for production of BMB, BMVC, BPC, and BMCS for roofing. The technology developed by IPIRTI has been transferred the to nearly ten industries in the country.

Kerala Bamboo Development Corporation established a Bamboo Board Factory in 1985 to produce value added products using bamboo mats as the main raw material. Commercial production started in 1990. At present, 21,500 square feet (1998 sq. metre) of bamboo ply on 4 mm basis is produced daily on an average in normal conditions of working. In 2011, the corporation also commissioned a hi-tech bamboo flooring unit in Kozikode, which uses bamboo as the main raw material. However the technology for making tiles was imported from China. The tiles are produced mainly in the size of 0.96 m x 0.096 m and thickness of 15 mm and 18 mm and the installed capacity is 1,44,000 sq. metres of bamboo flooring per annum. For optimum utilization of bamboo resource, bamboo waste generated at the flooring tile unit is used for production of other products such as tooth picks, window blinds and incense sticks, which are being manufactured at other feeder units at Kadampuzha, Palakkad, and Nadapuram respectively. In addition, the corporation also manufactures bamboo based furniture.

Timpack Pvt. Ltd. at Byrnihat in Meghalaya is another major bamboo-based industry manufacturing bamboo mat corrugated sheets and bamboo mat boards, the technologies developed by IPIRTI.

However, total present consumption of bamboo in these products is not very significant but some of these technologies have immense potential for bulk use of bamboo in making several vital products required by the society and with increasing population and rising standards of living their demand is bound to have an increasing trend.

7.9 Future Strategy

Based on a critical review of the bamboo processing and value-addition industry in India, the following steps are suggested:

7.9.1 Networking of industries

A cluster approach should be adopted for promoting the networking of various industries. Primary processing units specialising in specific steps of pre-product processing should be established near areas of bamboo production. These units must converge into big units doing secondary processing, which would, in turn, converge into bigger industries making finished products. This would reduce wastages, promote efficiency and develop expertise in specific steps thereby resulting in a significant drop in cost of production. District or block level clusters should be formed and common facilitation/ technology centres with machinery must be developed.

7.9.2 Raw material supply

Bamboo is crucial to the livelihood of artisans and cottage industries. Bamboo extracted from the forest must be sold to various buyers at competitive rates. Traditional artisans and high value-addition industries (*e.g.* handicrafts, furniture, structural usage, composites, incense sticks, textile, etc.) should be given bamboo from forests on a higher priority than low value-addition industries (*e.g*. pulp and paper, biofuel, etc.), other things being equal. Among high value-addition industries, the highest priority should be accorded to micro-enterprises (including cottage industries), followed by small, medium and large enterprises in decreasing order.

7.9.3 Processing

The industrial units should carry out processing in their niche areas to develop expertise. Raw material for their specific requirements should be sourced from respective cluster and produce disposed through the cluster.

- Mechanisation /semi-mechanization should be done in handicraft, agarbatti stick and furniture industries.
- Newer product must be identified based on regular market surveys in domestic and international markets and processing should be undertaken for those products too.

7.9.4 Quality control

Quality standards should be developed for semi-processed and value-added bamboo products; this would facilitate trade in these products across the cluster.

7.9.5 Research and development

- State-of-the-art technology and innovativeness should be used in bamboo processing and value addition. Research and development organisations, including IITs, are required to play a major role in this regard. Organizations, such as ICFRE, IPIRTI and major engineering institutions, must undertake research to develop appropriate and innovative technologies for bamboo harvesting, processing and value addition for specific species and products.
- Adequate infrastructural, manpower and financial support may be provided by the Government to agencies involved in research and development.

7.9.6 Backward and forward linkages

- Uninterrupted supply of water, electricity and chemicals for bamboo industry must be ensured in industrial centres. Suitable transport and communication services must be provided in bamboo value chain.
- Absence of proper grading and storage facilities hampers the procurement of bamboo by industries, often leading to damage and poor quality of harvested stock. Individuals, communities and agencies involved in harvest, grading, transport and storage must be educated about importance and methods of proper grading and storage. Warehousing and storage facilities, must be developed at strategic locations.
- A network of bamboo processing and value-addition artisans and industries may be created to link all connected with the bamboo sector. A special monthly bulletin or magazine may be launched.
- Digitized information on bamboo resources, producers, consumers, technology, market information, etc., ought to be placed online. Online marketing of bamboo semi-processed and value added bamboo should be promoted as it reduces the warehousing needs.
- Hurdles in any step from procurement of raw material to sale of finished product must be communicated to nodal agency on bamboo (currently NABM) and to ICFRE for addressing the problems

7.9.7 Tax relief

- Raw bamboo, and primary and secondary processed bamboo ought to be exempted from GST, or provided tax incentives on the lines of khadi, handloom and village industries.
- Incentives and subsidies should be given by the Government for specific applications of bamboo products with clear environmental advantages
- Raw bamboo, primary processed bamboo products and handicraft items ought to be exempted from GST. The rate of GST must be reduced on other products to promote bamboo sector on the lines of khadi, handloom and village industries.

7.9.8 Exim policies

- Import duty on processed and semi-processed bamboo must be increased. and anti-dumping duty ought to be imposed on cheaper imports of such products

7.9.9 Robust market mechanism

- Bamboo cooperatives must be formed to help people collectively take up raw material procurement processing, value addition and marketing.
- Business development help desk ought to be created at district or block level for providing information to artisans and industries engaged in bamboo processing and value addition on business counselling, market information, technology information and preparation of business plan.

7.9.10 Capacity and skill development

- Training programme for unemployed youth must be conducted under Pradhan Mantri Kaushal Vikas Yojana in leading forestry institutions. . Industrial training Institutes (ITI) should take necessary action to popularize bamboo processing and value addition.
- People in and around bamboo forests and other growers ought to be trained in bamboo processing and value addition
- Skill development programmes on bamboo processing and value addition must be product-specific as well as species-specific and conducted for target artisans and industries.
- Trainers training programmes should also be conducted.
- Institutions like FRI (Deemed) University, and its centres across the country, can initiate certificate and diploma courses in various aspects of bamboo technology, including bamboo processing and value-addition, with support from UGC and Ministry of Human Resource Development. The strong research support of ICFRE and other related organizations such as IPIRTI and CIBART would help to create a strong professional workforce.
- Trained bamboo entrepreneurs must be supported under "Startup India" programme of the Government of India to venture into bamboo entrepreneurship.
- The industry should get their workers trained at institutions specialising in bamboo processing and value addition.

7.10 Conclusion

India has the largest area under bamboo in the world but is facing shortage of bamboo raw material in its industries. For improving the bamboo sector, the regulatory restrictions on trade and transits need to be addressed. India can have 4-5 times bigger bamboo sector than now if bamboo production practices have proper market linkages. Thus, bamboo can play an important role in substituting for timber for housing, construction and varied products. Innovation, new technology and product options can encourage more number of manufacturers. Further, there is a need for product testing and quality control to increase market acceptability. There is a need to set up technology institution to train people about advanced bamboo technologies. Strengthening of research can tremendously help in the development of bamboo sector.

CHAPTER - 8

BAMBOO PRODUCTS

8.1 Introduction

Bamboo is perhaps the most versatile plant group in adaptability and utility. As young as 30-day-old bamboo shoots are used as food, shoots between 6-9 months are suitable for basketry, 2-3 years old culms are useful for laminates and boards and 3-6 years old culms are used for construction (Pandey and Shyamasundar, 2008). The major advantage of bamboo is that many products can be produced by small and medium scale enterprises. It has many domestic and agricultural uses, ranging from household utility products, ornamental uses to house construction (Muraleedharan *et al.*, 2001). This Chapter discusses few most prominent uses of bamboo.

8.2 Building Construction

Bamboos are utilized for a variety of purposes as they possess enormous bending and tensile strength. According to Liese (1985), the density of bamboo varies from about 0.5 to 0.8 g/cm^3. It is an indispensable material for construction and is used in round or split form for construction of foundations, frames, floors, walls, interior panelling, partitions, ceilings, doors, windows, shingles and pipes. The uses of bamboo for trusses have been elaborated by many workers. In a study, it was compared with steel, concrete and timber in terms of energy needed for production, safety, strength and stiffness as well as simplicity of production as a construction material. The comparison places bamboo well ahead of other for construction purposes.

Tewari (1992) summarized the characteristics of bamboo, which render it suitable for reinforcement in cement concrete constructions. There are three main types of bamboo houses:

1. traditional houses, which use bamboo culms as a primary building material,
2. traditional bahareque bamboo houses, in which a bamboo frame is plastered with cement or clay, and
3. modern pre-fabricated houses made of bamboo laminated boards, veneers and panels.

A very large population, especially in rural areas, in tropical and sub-tropical regions of the world lives in traditional bamboo houses. These houses are usually cheaper than wooden houses, light, strong and earthquake resistant, unlike brick or cement constructions. New types of pre-fabricated houses made of engineered bamboo have certain advantages. They can be packed flat and transported to long distances at a reasonable cost. They are better designed and happen to be environment friendly, besides being widely available and cultivated at a low cost.

Diverse uses of bamboo

Some important uses include making of anchors, bows and arrows, back scratchers, baskets, beds, boats, bridges, bottles, brooms, brushes, caps, cart yokes, ceilings, chairs, chicks, chopsticks, coffers, combs, containers, cooking utensils, doors and windows, dustpans, decorative articles, fans, fences, fish-traps, fishing nets, fishing-rods, flag poles, flutes, flower pots, food baskets, fuel, furniture, handicrafts, hedges, hookah-pipes, kites, ladders, lamps, loading vessels, match sticks, mats, milk vessels, musical instruments, nails, ornaments, pulp, paper, purlin, pens, parquet, rafts, rayon pulp, roofing, ropes, sails, scaffoldings, scoops, seed-drills, shuttles, spears, sport goods, sprayers, stools, sticks, tables, trusses, trays, toys, tool handles, traps, tubs, thatching, umbrella handles, walking sticks, wall plates, water vessels, wrappers, etc.

8.2.1 Pre-fabricated house using composites

Bamboo composite-based prefab structure is a temporary structure with characteristics of easy to erect and easy to transport. It takes shorter time for construction and has use for public as well at private places. Its life is 15 years. The structures are strong, durable, low in maintenance, fire retardant and have thermal insulation.

Wooden roof trusses, I-joists, walls and partitions have been traditionally important pre-fabricated components. Bamboo-based panels have properties similar to the wooden panels. The main advantage of modular houses is that they can be pre-fabricated in large quantities and easily transported to construction sites. IPIRTI bamboo composite panel-based pre-fabricated houses can be efficiently transported in 'one pack' and assembled quickly. Such technology would be highly relevant in particular for relief agencies for disaster management.

These houses are cheaper than traditional wooden houses, and are light, strong and earthquake resistant. They can be packed flat, transported, and are environment friendly. There has been improvement in the preservation and protection technology of bamboo as well as in jointing techniques so that the use of bamboo can be proliferated as construction material. These technologies are helping in increasing the durability of bamboo as construction material. Advances in structural engineering and the development of bamboo composites have opened new areas for lightweight, durable and aesthetic construction for a variety of applications with proper treatment. Forest Research Institute, Dehradun, Indian Plywood Industry Research and Training Institute, Technology Information Forecasting and Assessment Council, Building Material and Technology Promotion Council, etc. are coming up with latest, innovative, cost-effective and eco-friendly bamboo-based products that can be used in construction application.

Such structures have been structurally tested by NMBA supported programme and erected at Kargil, Leh (Jammu and Kashmir), Port Blair, Car Nicobar (Andamans), Khamman (Andhra Pradesh), Guwahati, Tezpur, Dinjan, Bodoland (Assam), Ruksin, Pasighat, Lumla (Arunachal Pradesh), Patna (Bihar), Dantewada (Chhattisgarh), Delhi, Chamba (Himachal Pradesh), Agartala (Tripura), Amethi (U.P.), Haldwani, Joshimath, Ranikhet, Dehradun (Uttarakhand), Kalimpong, Dinhatta (West Bengal), Kisama and Dimapur (Nagaland).

8.3 Flooring

Bamboo flooring is a quality product that can be used widely and has a large, global consumer market. It has certain advantages over wooden floors due to its smoothness, brightness, stability, high resistance, insulation qualities and flexibility. Bamboo flooring has advantage of natural lustre and maintains the natural gloss and elegance of bamboo fibre. This flooring is attractive to the demanding markets in Europe, Japan and North America. The estimated annual production of bamboo flooring in China was 17.5 million square metres in 2004. Exports account for some 65 per cent of total production. Although bamboo flooring units have been set up by the Kerala State Bamboo Corporation, constraints of raw material availability and inefficient marketing have resulted in bringing it to a standstill. Other private units have been established and it remains to be seen how they fare in the prevailing conditions. Most builders, architects and engineers are unaware of the product availability in India.

8.4 Handicrafts

Bamboo crafts and woven mats are traditional products in China, India, Malaysia, Philippines and Thailand. The technique has been known for several thousand years. These diverse products have become an indispensable part of daily life, literature and art. There are nearly 20 categories of woven bamboo products in Asia, including fruit baskets, trays, bottles, jars, boxes, cases, bowls, fans, screens, curtains, cushions, lampshades and lanterns.

Bamboo handicraft is predominant in the Indian handicrafts market and millions of people depend on bamboo for part subsistence or are fully dependent for their income. According to International Trade Centre (1999) handcraft items are artisan products which are produced by artisans, either completely by hand or with the help of tools or even by mechanical means. However, the most substantial component of the finished products is from the direct manual contribution by artisans. Bamboo-based industrial production is carried out both in the traditional and non-traditional sectors.

In the traditional sector, production of mats and baskets is the major activity. Non-traditional sector mainly involves and production of other handicraft products. The incomes generated from bamboo handicraft production are very low when compared to other employment opportunities.

Bamboo in India generates 432 million workdays annually. Some 25,000 bamboo-based industries provide employment to about 20 million people. The potential of bamboo handicrafts has not been properly tapped, especially in the export market. Intermediaries play an important role in the industry, which often hinders its progress (Anitha, 2009).

Case study: Andhra Pradesh and Telangana

In Andhra Pradesh and Telangana, the supply of bamboo to the handicraft and traditional sector, mainly basket weaving communities (Buroods), is met by the state forest departments. In the year 2014-15, Telangana Forest Department supplied 31,75,916 bamboos to buroods (TFD Annual Administration Report, 2015). *Dendrocalamus strictus* is the major species available in these states, which is suitable to meet the requirement of sticks for agarabatti industry. Only about 25-30 per cent of this bamboo species is suitable for slicing for mat weaving industry and for making slats for further conversion to wood for furniture for use in any other applications. The main handicrafts items are baskets, winnows, bamboo fan, ladder, mat among others and sometimes they produce bamboo fence and scaffolding stand.

The agarbatthi stick making is an important bamboo based activity in Andhra Pradesh and Telangana. Most of these units are small scale and to a large extent is a formal sector. These units are mainly located in Mancherial, Kagaznagar, Bellampally, Jananram, Madaram, Khammam, etc. A number of common facility centres are managed by Vana Samrakshana Samithies (VSSs or forest protection committees) which are involved in marketing of the products of VSS clusters. Bamboo is available from the forest areas under management of VSS and bamboo culms are supplied by the SFDs through their bamboo depots. Major agarabatthi manufacturing industries like ITC source their bamboo sticks mainly from these areas providing large scale employment opportunities.

Case study: Karnataka

In Karnataka, various types of bamboo products like fancy items, utility, furniture, and household items baskets, ladders, winnows, fences and intermediary items like agarbatti sticks and silk worm rearing tray are made. Sericulture sector is utilizing woven bamboo on a large scale. The main raw materials of silk worm rearing tray are bamboo mat, bamboo strips, stumps and coir. The SFD provides the bamboos to medars, buroods and other agencies through auctions and retail sale. There are about 950 artisans registered with the Development Commissioner (Handicrafts), who are engaged in bamboo-based handicraft activities. In the year 2016-17, the SFD supplied 2,68,802 culms of bamboo to medars and other organizations. The informal bamboo handicraft industry in Karnataka generates large employment opportunities in the State. Kodagu, Canara, Dharwad and Mangaluru are the major hubs for bamboo-based handicraft sector. Bamboo is also procured by the industry from the local markets and even from outside the State.

Case study: Tamil Nadu

In Tamil Nadu, approx. 800-1000 families work in informal sector of bamboo handicraft industry, based on the data available from Development Commissioner (handicrafts). They are traditional skilled, artisans engaged in the production of bamboo items like baskets, winnows, ladder, bamboo fans, mats, window screen, etc. Bamboo resource is sourced from natural areas and markets. The wages of artisans depends upon their production and price of commodities and their actual earnings per day is approx. Rs. 100-200. Since weaving is an art learnt by rural poor communities through generations, the employment generation in this type of use is quite high.

Various Bamboo Based Products Developed at IPIRTI, Bangalore

I Bamboo mat-based product


BMB


BMVC


BMC


BMMSD


BMCS


BMRC


Bamboo Mat Tray

II Bamboo strip-based product


Horizontal Laminate


Bamboo floor tiles


Vertical Laminate

III Bamboo lumber-based products

Bamboo Housing

Prefabricated BMB wood shelter

IPITRI-TRADA Housing Technology

Pre fab house at IPIRTI

IPITRI-TRADA Two bedroom Guest House

Case study: Kerala

In Kerala state, nearly two-thirds of the bamboo is extracted from the home gardens rather than forests (Krishnankutty, 2005). The Kerala Bamboo Development Corporation (KSBC) plays a major role in supplying the bamboos to the artisans in the state. KSBC has about 100 depots spread over Kerala. Bamboo supports a number of traditional cottage industries. Majority of the handicraft units in the State are traditional small scale cottage industry using simple tools and traditional methods at all stages of production. There are about 1000 artisans registered with the State Development Commissioner (Handicraft) specifically make bamboo-based handicrafts. The cottage industry lacks any significant mechanization. Uravu is a major NGO located in Thrikkaipetta village, Wayanad district, Kerala and works on bamboo handicrafts like bamboo blinds, bamboo folders, jewellery, etc. The focus of the NGO is on developing bamboo processing skills among rural women through training programs and introduction of appropriate tools, technologies and processes. Since its inception in 1996, it has provided training in bamboo handicrafts to over 1000 women in different parts of Kerala and the neighbouring states. The NGO has promoted the establishment of a micro-enterprise for bamboo crafts and is the implementing agency for the Kalpetta Bamboo Cluster programme which is a network of artisans, micro-enterprises, self-help groups, bamboo farmers, bamboo cutters and other stakeholders using bamboo as a resource for livelihood sustenance, value addition and income generation.

Bamboo handicrafts: North-Eastern region

North-east region is known for a vibrant bamboo culture and amazing bamboo handicrafts. It is a very important source of livelihood in the region. The products vary from tribe to tribe with unique designs, size and choice of colours.

Tripura ranks first in production of various bamboo crafts followed by Manipur. The bamboo and cane products in Tripura are quite unique in design and style; common products are dulla (fish basket), pathee (rain shield), kula, dala, trays, pencil holders, lamp shades, table mats, decorative fans, door screens, stools, vegetable baskets, shopping bags and so on. The popular products in Manipur include baskets, furniture, trays, mats, flower vases, fishing traps, etc. In Assam, products like variety of baskets, mats, hats, toys and dolls, etc are common and this is an important part time employment option. The bamboo hat or jhapi is a very famous handicraft product of Assam available in very attractive and bright colours. Other items like chalani, kula, dukula, khoralu, dhol and doon are also crafted out of bamboo in Assam which are widely used as household items. Arunachal Pradesh is known for products like smoking pipes, trays, knives, baskets, ornaments, barrels, storage pouches, etc. Baskets have distinct style and nomenclatures like barsi is an open-weaved basket; rothak and pathu are rectangle-shaped long bamboo pouches. Khoks/artistic baskets, bamboo houses, mats, stools, kurup (or a special type of Khasi umbrella) are some of the major bamboo/cane products produced in Meghalaya. Likewise, pipes, toys, hats, umbrella handles, fish baskets, mugs, weaving tools etc are commonly made handicraft items in Mizoram. In Nagaland, bamboo furniture like tables, chairs, sofas and cots are made by artisans. Sikkim is famous for bamboo/cane crafts such as showpieces, mats, baskets, furniture, etc. (Source: Moupee Debroy, www.nelive.in/north-east/business/ bamboocane-crafts-northeast-india, accessed on 11 Sep 2017).

The bamboo handicraft sector remains largely informal, which is the major factor limiting its growth on an industrial scale. Major constraints faced by the traditional artisans are given in Table 8.1.

Table 8.1. Constraints faced by handicrafts sector

Main area	Constraints
Raw material acquisition	• Limited availability • High price per culm/ bundle • Seasonal availability of culms
Production	• Traditional tools and implements • Lack of mechanization making the process time-consuming • Labour intensive techniques • Lack of scientific methods of treatment/ preservation
Products	• Mostly traditional products (winnows, baskets) • Low quality • No product diversification
Marketing	• Seasonal demand and prices for traditional products • No proper mechanisms for price-fixing • No stable markets
Training	• No formal training received (only traditional skills) • Lack of proper facilities and machinery in the co-operative societies/ lack of social security for workers • Unregistered SSI units without proper coordination

(Source: Anitha, 2013)

8.5 Pulp and Paper

Bamboo forms an excellent raw material for pulp and paper industries. In the past it used to form almost 40 per cent of the total raw material requirement of paper industry in Andhra Pradesh. However with the change of technology and limited availability, hardwoods has largely replaced bamboo. The paper industries in the State are progressively reducing their requirement of bamboo. In terms of potential for value addition, the use of bamboo for paper and pulp under the prevailing conditions is not to be promoted unless famers are benefitted in getting fair prices.The main advantages of using bamboo as a raw material include:

- Fast growth rate
- No debarking required and hence, less energy consumption
- High yield from kraft pulping
- Low chemical consumption
- Easily bleachable kraft pulp
- Strong pulp (stronger than most tropical hardwood pulps)
- Bamboo pulp is suitable for a broad range of paper grades

8.5.1 Anatomical and chemical characteristics

Anatomical characteristics and chemical composition are very important from point of view of pulp and paper making. Bamboo is composed of mainly two types of tissues, namely fibres and vessels arranged in clusters of fibro-vascular bundles loosely interspersed in a continuous medium of the parenchyma cell tissue. The fibre filaments constitute about 60 to 70 per cent (on weight basis) and the parenchyma cells about 40 to 30 per cent of bamboo. Bamboo, like a long-fibre timber, has an average fibre length of 2 mm and fibre content of 40-60 per cent. Fibre length of species varies from 1.01 mm in *Arundinaria* sp. to 3.36 mm in *D. hamiltonii. D. strictus* is the most widely used for papermaking and its fibre length is 3.06 mm. Other important species for paper making include *Bambusa arundinacea* (syn. *B. bambos*), *Melocanna baccifera* (Syn. *M. Bambusoides*), *B. tulda, B. vulgaris, D. hamiltonii, B. nutans, Ochlandra travancorica, O. scriptoria* and *O. reedii*. The proximate chemical composition of bamboo is similar to that of hardwoods, except for the higher alkaline extract, ash and silica contents.

8.5.2 Paper mills

Paper containing pure bamboo pulp can be made without any difficulty. However, with the expansion of the Indian paper industry and declining supplies of bamboo coupled with use of recycled paper, agricultural residue and the abundant tropical forest in the country, the industry has begun to mix hardwood pulp with bamboo pulp for production of paper. Some of the industries which are using bamboo pulp as a whole or in combination with hardwood pulp are listed in Table 8.2.

Nagaon Paper Mill, a unit of Hindustan Paper Corporation Ltd., is one of the largest paper mills in India with capacity of 1,00,000 tonnes per annum. The mill requires 4.50 lakh tonne bamboo in a year to meet the production target. Although there are enough raw material now, still the mill has adopted the farm forestry scheme for raising bamboo and other pulpwood species since 1987-88. This scheme ensures the enough supply of raw material and also generates youth employment maintaining ecological balance and improving rural economy. The main objectives of this scheme are to increase productivity, uplift economy of local people, generate employment of local youths, and establish an agro-silvicultural system (Nedfi Databank, file:///F:/AssamOnTheRise%20-%20Assam%20Online% 20Portal. Html).

Table 8.2: Important paper industries using bamboo as a raw material

S. No.	Industry	State
1.	Sirpur Paper Mills Limited	Andhra Pradesh
2.	Ballarpur Industries Limited (unit Ballarpur)	Haryana
3.	The Mysore Paper Mills Limited	Karnataka
4.	Shree Swami Harigiri Paper Mills Limited	Gujarat
5.	Seshasayee Paper & Board Limited	Tamil Nadu
6.	Orient Paper Mills Limited	Odisha
7.	Bengal Paper Mills Co. Limited	West Bengal
8.	West Coast Paper Mills Limited	Karnataka
9.	Nagaon Paper Mill (Hindustan Paper Corporation Limited)	Assam
10.	Cachar Paper Mill (Hindustan Paper Corporation Limited)	-do-
11.	Hindustan Newsprint Ltd. (Hindustan Paper Corporation Limited)	Kerala

*Source: Panda, 2011; Jain *et al.,* 2015

8.5.3 Major constraints as a raw material for paper making

The major drawback of using bamboo is its high silicon content (about 60 per cent of ash). Pulp and paper making processes such as material preparation, digester operation, brown stock, chemical recovery system, recausticising and paper machine operations are adversely affected by the presence of silica in bamboo. The limitations are aggravated by low fibre and pulp yield per ha per year of bamboo in comparison with other raw materials used (Table 8.3). Also, there are some other bottlenecks in using bamboo, which include:

- Gregarious and sporadic flowering which upset and disrupts regular supply
- Difficult to chip due to hollow stem
- Difficult to handle mechanically because of variable diameter and crookedness of stem
- Dense nodes, which are highly lignified and difficult to pulp
- High percentage of parenchyma cells

8.5.4 Major prospects in pulp and paper making

Bamboo is an excellent material for making high-quality paper. Genetic modification and breeding of bamboos is under progress to facilitate the pulp and fibre yield. Durable, cold- and drought-resistant bamboo production is still under research. By combining biotechnology and modern tissue culture with conventional propagation techniques, generation of modified hybrids have become convenient and less time consuming at present (Zhang and Guangchu, 2002). Genetically improved plants will hopefully provide a prospective future of bamboo in pulp and paper technology. In India also selection of quality germplasm of 10-15 species and its multiplication is under progress at ICFRE Institutes.

8.6 Furniture

Traditional bamboo furniture uses natural round or split bamboo. A new type of 'pack-flat' 'knock-down' furniture uses glue-laminated bamboo panels. Unlike the traditional design, this furniture may be shipped in compact flat packs, to be assembled on the spot. The new design overcomes many of the problems of traditional bamboo furniture, such as high labour and transportation costs, low productivity, instability, varying quality and susceptibility to insects and fungi. At the same time, it retains the distinct physical, mechanical, chemical, environmental and aesthetic features of bamboo. Bamboo in the whole culm form can also be used in furniture if species with solid/near-solid culms like *D. stocksii, D. strictus* and *T. oliverii* can be used with appropriate mechanical processing. High end furniture of the type designed by National Institute of Design, Bengaluru and manufactured by Konbac Ltd., Kudal, Maharashtra and others also have tremendous potential. Export of laminated bamboo furniture is growing rapidly. However, trade statistics currently do not capture the value, owing to the absence of a special code for bamboo furniture. It is usually classified as wooden furniture.

8.7. Fabrics

Economical, ecological, aesthetically pleasing, comfortable and long-lasting bamboo fabric is going to be in high demand in future due to its antibacterial properties that can be ascribed to the presence of an anti-bacterial bio-agent called 'bamboo-kun' bound closely in the bamboo cells. Bamboo fabric is breathable (remains odourless even when attacked by odour-causing bacteria) and absorbent and does not cling to skin. This fabric is particularly good for people with skin allergies. The forest bamboo that was earlier being used in manufacturing paper can be easily used for making bamboo fabric. However, a detailed techno-economic feasibility study is required to be done. Under-utilization of the potential of bamboo may be ascribed to technical knowledge deficit at various levels, inadequate marketing network in addition to continued lack of policy push.

"Bamboo should become the lifestyle of the general consumer in India. The Govt of India should bring focus on creating good raw material, application of bamboo through design and also development of technology to enable quality production"

- C.S. Sushant, Faculty, National Institute of Design, Bengaluru,

8.8 Food and Nutraceuticals

Bamboo shoot is young, immature, expanding culm that emerges from nodes of the rhizome of plants. It is harvested shortly after it appears above the soil surface. The edible part consists of tissue with regions of rapid cell division, which is enveloped in a protective, non-edible leaf sheaths (Farrelly, 1984). Fresh shoots have a crispy crunchy texture and a unique taste. Worldwide, more than two million tonnes bamboo shoots are consumed annually of which about 1.3 million tonnes are produced in China alone (Kleinhenz *et al.*, 2000). In India, not much importance has been given to its usage as food item. Consumption of tender shoots is confined mainly to the north-eastern states and few parts of central, eastern and southern India where they are part of the traditional cuisine.

In India, particularly the people of north-east regions have been consuming bamboo shoots either raw or processed because of its exotic taste, flavour and medicinal value (Madhab, 2003; RFRI, 2008; Basumatary *et al.*, 2017). In central, eastern and other parts of India, bamboo shoots are consumed mainly by tribals. Normally people harvest bamboo shoots for their own consumption but in some areas they are being sold in the market. However the actual availability of edible fresh bamboo shoots is very limited in a year. Since shooting season for a bamboo generally lasts only for 1-4 months. Major edible bamboo species consumed in India are listed in Table 8.4. *D. apser* is the most important species for shoot production in Thailand (Fu *et al.*, 1987) and is also planted in few places in Madhya Pradesh, Chhattisgarh, Maharashtra and Karnataka.

Table 8.4: Edible bamboo species available in different parts of India.

Region	Bamboo species	References
South India	*Arundinaria aristata, A. hirstuta, D. brandisii, B. arundinacea, B. glaucescens, B. longispiculata, B. vulgaris,*	Chauhan *et al.* (2016) Chandramouli and Viswanath (2012)
	Cephalostachyum capitatum, C. fuchsianum, D. hookeri, Oxytenanthera albociliata	NMBA (2011)
Central India	*D. strictus, B. bambos, B. tulda*	Pandey and Ojha (2011)
Eastern India	*D. strictus, B. bambos, B. tulda, B. nutans*	Pandey and Ojha (2011)

Over two million tonnes juvenile bamboo shoots are consumed in the world annually (Yang *et al.*, 2008). The USA alone imports over 14.5 per cent of the world bamboo shoots mostly from Asia, promoting an estimated US$ 18 billion trade industry (Daphne, 1996; Lobovikov, 2003). In the north-eastern states of India, 1979 tonnes of fermented bamboo shoots are consumed annually (Bhatt *et al.*, 2004; Singh *et al.*, 2010). Major edible bamboo species consumed in north-eastern region are listed in Table 8.5. Bamboo shoots of Tripura have huge demand in Indian hotels and abroad. The annual estimated consumption of the shoots in Tripura State is over 20,000 tonnes. The State Forest Department of Tripura has banned commercial purchase and sale of indigenous varieties of bamboo shoots to stop rampant destruction of the bamboo forest cover in the State (Times of India, 2016).

Table 8.5: Edible bamboo species available in different parts of India.

State	Bamboo species	Annual consumption (tonne)	References
Assam	*B. burmanica, B. pallida, B. tulda, D. hookerii, D. giganteus, D. sikkimensis, Gigantochloa rostrata, G. albociliata, M. baccifera, P. bambusoides, Schizostachyum dullooa.*	-	Bhatt *et al.* (2004)
Arunachal Pradesh	*B. nutans, B. pallida, Chimonobambusa callosa, D. giganteus, D. hamiltonii, G. albociliata, Pleioblastus simonii, Sinarundinaria elegans*	1,978	
Manipur	*Chimonobambusa. callosa, D. asper, D. hamiltonii, D. longispathus, D. strictus, D. giganteus, D. latiflorus, D. flagellifer, M. baccifera, B. bambos, B. nutans, B. kingiana, B. nana, P. heterocycla var. pubescence, P. bambusoides, Schizostchyum beddomei*	2,187	Bhatt *et al.* (2004)
Meghalaya	*D. hamiltonii, D. calostachyus, D. hookerii, D. sikkimensis, G. albociliata, G. apus, G. rostrata, Schizostachyum dullooa, M. baccifera*	4,418	
Mizoram	*P. mannii, B. longispiculata, M. baccifera, B. pallida, B. tulda, Chimonobambusa callosa, D. calostachysus, D. hamiltonii, D. hookeri, D. sikkimensis*	433	
Nagaland	*B. pallida, B. tulda, Chimonobambusa callossa, D. calostachyus, D. giganteus, D. hamiltonii, D. hookerii, D. sikkimensis, Sinarundinaria elegans*	441	
Tripura	*B. pallida, B. tulda, B. polymorpha, D. hamiltonii, D. longispathus, G. rostrata, M. baccifera,*	201	
Sikkim	*D. hamiltonii, D. hookeri, D. sikkimensis*		

8.8.1 Health benefits

The main nutrients in bamboo shoots are protein, carbohydrates, amino acids, minerals, fat, sugar, fibre, and inorganic salts. The shoots have a good profile of minerals, consisting mainly of potassium (K), calcium (Ca), manganese (Mn), zinc (Zn), chromium (Ch), copper (Cu), iron (Fe), and lower amounts of phosphorus (P), and selenium (Se) (Nirmala *et al.*, 2007). Fresh shoots are a good source of thiamine, niacin, vitamin A, vitamin B6, vitamin C and vitamin E. Bamboo shoots also contain high proportion of linoleic acid. The major fatty acid in bamboo shoots is palmitic acid. Glutamic acid and lysine are other abundant amino acids found in bamboo shoots. As a dietary fibre source, the shoots have beneficial effects on lipid profile and bowel function.

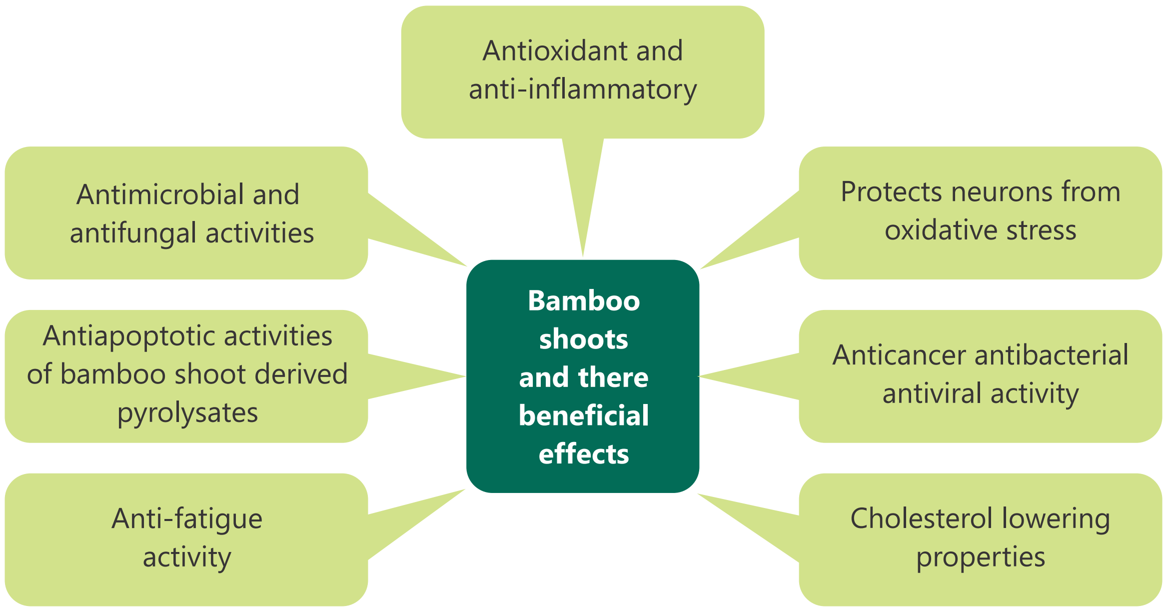


Fig. 1: Health benefits of bamboo shoots

The health benefits of the young shoots are attributed to the presence of bioactive compounds mainly phenols, phytosterols and dietary fibres, which play a potential role in health promotion and providing protection against many chronic and degenerative diseases. Bamboo shoots contain high level of phytosterols, playing a key role in lowering blood cholesterol and high levels of cellulosic content, an important appetizer (Park and Jhon, 2009; Nirmala *et al.*, 2011), anti-fatigue activity (Akao *et al.*, 2004), high levels of antioxidant activity, micro-minerals, macro-minerals and high protein levels per gram of dry weight (Waikhom *et al.,* 2013; Waikhom *et al.,* 2015).

8.8.2 Fermented shoots

Fresh shoots are found only during growing season*, i.e.*, July to September and so people ferment the shoots by traditional methods for use during offseason. Fermented bamboo shoots are highly prized vegetable items consumed throughout the year and are traditionally prepared by cutting thin slices of bamboo shoots and pressing it tightly either in earthen pots or in bamboo baskets for a minimum period of three months.

The two popular fermented forms of Manipur are soibum and soidon. These are available in the market throughout the year and used as vegetables or additives for making different delicious dishes. Fermented shoots of 114.3 tonnes per year are sold in the markets and a net income of 3.8 million rupees per year has been earned by selling fermented bamboo shoots (Bhatt *et al,* 2003 & 2005). Shoots of *B. nutans, B. tulda, D. giganteus, D. hamiltonii, D. sikkimensis, C. capitatum,* etc., are largely used for fermentation.

8.8.3 Value-addition to shoots

Value-addition to bamboo can be done by making different edible products which can lead to cultivation of bamboo shoots by the farmers and help in poverty alleviation and income generation. The shoots are used as food in various ways and forms such as fresh, dried, preserved, shredded or pickled. Moreover, they are used as extender as they take on the flavour of the ingredients they are cooked with. Different types of preparations such as bamboo shoot curry, chutney, bamboo candy, pickle, fried shoots, pulav, keema, manchurian, soup, bamboo canned juice, and bamboo beer are made from bamboo shoots. Bamboo vinegar is also used as flavouring vegetables and medicine for stomach disorders (ERG, 2003).

Sofa

Handicraft

Treated bamboo hut

Sofa

Packing box

Bag

Table

Tray

Shoe Rack

Various products made from bamboo at FRI, Dehradun

Value-addition method for bamboo shoots:
Fresh shoots → removing the hard outer sheaths → washing → cutting into small pieces → pulping → mixing with pulses/starch → extruding the mixture → extruding into sticks → cool and keep for 8-12 hours → slicing → drying → frying → reducing the oil content → seasoning → packing → final product

Canned bamboo shoots can be satisfactorily preserved and used frequently in various food items such as vegetables or pickle condiments (Sood, 2013). Bamboo shoot powder offers several advantages such as low moisture content, free-flowing, ease of handling and weighing, reduced storage space, ease of cleaning and sanitary aspects. It could be directly used into various dry food items and preparing chutney and beverages.

Value addition has been done in bamboo shoots by making different products such as bari, papad, pickle, sauce and crunches at TFRI, Jabalpur. Value-addition in bamboo shoots has increased their nutritional value and will also increase their marketability. The above value added products were good in taste and texture having a shelf life of 6 months from the processing date (Pandey *et al.*, 2012).

8.8.4 Potential

In India, according to an estimate by the National Mission on Bamboo Application (NMBA) and Trade Development under the Planning Commission of India, the Indian bamboo shoots industry has a potential to grow at an exponential rate of 25 per cent per annum and is expected to garner a market worth Rs. 3,330 million annually.

Worldwide commercial bamboo shoot utilization is reported to be 20 million tonnes per annum. More than half of this amount is harvested and utilized by poor people in rural areas. Considering the bamboo shoot quality and safety aspect together, suitable processing and preservation methods integrating indigenous knowledge system and modern scientific inputs, needs to be developed.

8.8.5 Perspectives

In spite of the fact that bamboo shoot has been an integral part of diet of tribal community i.e., scientific validation of traditional processing methods in terms of food quality and safety has not been attempted and this demands adequate attention apart from scientific standardization of the processing technologies as well as product recipes for various bamboo shoots based food products. In order to design appropriate machinery for processing of bamboo shoot such as slicing, striping, sizing and physical characteristics especially shear properties play very important role. Canning has been perceived to be effective in reducing rancidity and thus, preventing the growth of micro-organisms in bamboo shoots. There is a need to develop processing technologies to preserve the bamboo shoots in consistent and imperishable forms to be used during off-season While considering the nutraceutical values of edible bamboo shoots and the toxicity implications, dietary intake of proteins and other nutrients can be a deciding factor in the regions of low nutritional diet. Hence, use of appropriate species of juvenile edible bamboo shoots is the solution for food security as well as a potential source for income.

8.9. Charcoal (Multiple Uses)

Bamboo charcoal is traditionally used as a substitute for wood charcoal or mineral coal. It can serve as a fuel, absorbent and conductor. Activated bamboo charcoal can be used for cleaning the environment, absorbing excess moisture and producing medicines. The absorption capacity of bamboo charcoal is six times that of wood charcoal of the same weight. China is a leader in charcoal production. At present, Japan, the Republic of Korea and Taiwan are the main consumers, but its import is rapidly expanding in Europe and North America. In many parts of Europe, bamboo charcoal is used in water purifying, where it is considered a superior option. In Ethiopia, the bamboo is largely used for charcoal making. There are three main reasons contributing to the success of bamboo charcoal in international trade:

- Bamboo grows faster and has a shorter rotation compared with tree species;
- The calorific value and absorption properties of bamboo charcoal are similar to or better than those of wood charcoal
- It is cheaper and easier to produce.

a) Charcoal as adsorbent: Charcoal obtained from pyrolysis of bamboo biomass is known to possess high surface area and better absorption properties than wood charcoal (Bardhan *et al.,* 2014). This makes it beneficial for various biomedical applications. Bamboo charcoal coated with nano-particles spinel ferrite forming a core- shell structure, and introduced into epoxy resin was found to be a microwave and infrared energy absorber. Bamboo charcoal is capable of adsorbing toxin in blood as well, and hence, is useful in blood purification process. Chou *et al.* (2015) reported the effectiveness of bamboo charcoal for removal of Ciprofloxacin, which is largely available in pharmaceutical industrial waste. The adsorption capacity of this charcoal was found to be 613 mg/g much higher than charcoal obtained from other sources.

b) Other uses : Anti-bacterial property of bamboo charcoal was reported by Choi and Ahn (2014). Growth of S. nutans reduced by 58 per cent on bamboo charcoal medium (Concentration: 2 per cent and 5 per cent). Yang *et al.* (2009) reported the high antibacterial efficiency of bamboo silver composites. With 18 hours of inoculation, Bacterial colonies of Gram-positive S. aureus were found to be completely killed and with complete the percentage reduction of bacterial growth. In addition to this, the mixture showed strong antibacterial properties against Ciprofloxacin-resistant *P. aeruginosa, E. coli* and *B. subtilis* bacteria.

Studies by Ling *et al.* (2011) showed that roof tops spread with bamboo based charcoal with lower temperature compared to non-green roof tops. Comparison of heat fluxes of conventional roof top and bamboo charcoal roof top showed that 10 per cent reduction in temperature during summer months.

8.10 Bioenergy

Bamboo is one of the fastest growing plant species on the earth and can solve energy problems as it has calorific value of about 19 MJ/kg or 4,500 kcal/kg, low ash and alkali content and C and H values similar to wood. The calorific value of bamboo charcoal is 26-29 MJ/kg or about 6,600 kcal/kg. The bulk density is low. Densification or briquetting is necessary.

8.10.1 Charcoal as fuel

The calorific value of bamboo charcoal is almost half that of oil of the same weight. At the time of cut to length of culms slating, re-slating, silvering and stick production, at least 40 per cent waste generally occurs, *i.e.*, node and internodes, etc. This waste can be further reused as value added products such as waste bamboo charcoal for making bamboo briquettes and used in agarbatti masala. TRIBAC-INBAR led Drum Charcoal production technology can be used in for production of charcoal. It is low cost community friendly technology and easily manageable by community. The operation and management cost is less. The tribal women in rural areas can take lead to set up enterprise.

Most of the Indian charcoal manufacturers still use the highly polluting and inefficient 'pit' method for charcoal production from bamboo waste. To overcome, IIT, Mumbai has developed a simple to operate, non-polluting Bio-Char Unit (BCU) under the National Mission on Bamboo Applications (NMBA), TIFAC, Dept., of Science and Technology. Using BCU, a uniform yield of 25 per cent charcoal from bamboo waste can be achieved. A batch of 100 kg bamboo waste is converted into 25 kg charcoal in two and a half hours. A single person can operate the unit.

A bio-char unit was set up in an activated carbon manufacturing plant in Hyderabad, where the suitability of bamboo charcoal as raw material was successfully demonstrated. Another BCU sponsored by KVIC is being put up at a bakery unit at Yusuf Mehrauli Centre, Tara Village, Maharashtra to demonstrate the use of thermal energy from gases for generating charcoal as a by-product. Through NMBA, 15 such units at five different locations in Tripura, Meghalaya, Bastar, Amravati and Pune districts has been established for training and further dissemination of the technology. The BCU is expected to help generate rural employment, and ensure village energy security.

8.10.2 Feedstock in gasifier

Bamboo in general seems to be a satisfying feed-stock for a downdraft gasifier because of its acceptable heating value, low ash content and low sulphur content. According to this study B. oldhamii and D. strictus seem to have the best qualities for gasification. Gasification of bamboo can produce energy and a range of valuable by-products. It reinforces a commitment to clean and renewable electricity and thermal energy. It can utilise waste generated by processing operations, substitute the use of fossil fuels, and lower operating costs. Bamboo can be cut into small pieces and used in the gasifier. The requirements for the gasification units are a small proportion of the total availability.

A 100 KW gasifier would require only about 1000 tonnes per annum, the equivalent of a truckload every three days on the average. An added advantage of gasification of bamboo is that 15 per cent of the biomass would also be available as a by-product in the form of high grade charcoal. In the case of a 100 KW gasifier, around 135 tonnes of charcoal would be available each year to meet local needs of fuel. It is clean, cheap & renewable source of energy. Further, it does not depend on quality, species, and maturity of bamboo.

8.10.3 Bioethanol production

India is the second largest producer of bamboo in the world with an annual production of about 32 million tonnes. About 5.4 million tonnes of bamboo residues are generated in the country every year by the bamboo processing industries, of which about 3.3 million tonnes remains as surplus and has potential of producing about 473 millilitres ethanol (Kuttiraja *et al.*, 2013). *Dendrocalamus* sp. occupies more than 50 per cent of the total area under bamboo growth in India and has been found suitable species for bioethanol production due to relatively higher growth rate, their abundance and sustainable availability (Kuttiraja *et al.*, 2013). Compared to other feedstock, bamboo biomass has a relatively high cellulose and low lignin content which makes it suitable for bioethanol production.

A pilot project was conceptualized on the use of bamboo dust waste for Cachar Paper Mill located in the state of Assam. It uses almost 2,00,000 BDMT of bamboo annually for the production of 1,00,000 million tonnes of paper and generates about 35-40 tons of bamboo dust every day. This project was conceived to economically generate electricity by utilizing producer gas derived from a gasifier by means of a gas engine coupled with an alternator, thus contributing its share towards renewable energy in the country. An economic viability study has been carried out by calculating the cost of generation of electricity for the plant to produce this green energy as against that of convention coal fired stream generation (Sinha *et al.*, 2011).

In Gujarat, INBAR has initiated a project where householders have become shareholders in a bamboo power plant. The plant is run throughout the day and generates electricity for household energy, water pumping and a local flour mill. It has 30 per cent ownership by women who have been encouraged through the project to grow bamboo. DST/ NMBA approved establishment of a 25 KWe (35 kg/ hour) bamboo-based gasifier to provide electricity for a residential educational establishment (Central Institute of Himalayan Culture Studies, Dahung) in Arunachal Pradesh.

The Ministry of New and Renewable Energy Sources (MNRE), NMBA (National Mission on Bamboo Application) and Indian Institute of Science, Bengaluru have studied the feasibility of bamboo for power generation in both dual fuel and 100 per cent gas based engine. It has been found that in the initial phase it is ideal for the places where bamboo already grows on a large scale and bamboo processing industries are available. In the later phase it can be adopted in other conditions too.

Numaligarh Refinery Limited, in collaboration with Chempolis Ltd., a Finland-based bio-refining technology company, agreed to set up a bioethanol plant in Assam using bamboo as major raw material. A partnership agreement for this was signed by two companies in Finland on October 15, 2014. As per the agreement with Numaligarh Refinery Ltd. (NRL), the planned biorefinery will utilise bamboo (which is abundantly available in Assam) as main biomass for producing bioethanol and other products (Business Standard, 2014). This is a second major collaboration between the Finnish firm and an Indian PSU. In October 2013, Chempolis had signed an MoU with ONGC to explore the possibility of setting up a biorefinery project in India.

India has so far signed 15 supply contracts for bamboo-based ethanol as part of the government's push towards diversification of biofuel feedstocks. India is closer to get bamboo-based ethanol policy (Indian Express, 19 July 2017).

8.10.4 Future prospects

- Demonstrate and promote bamboo based charcoal and briquetting enterprise to replace wood charcoal.
- Devise certification systems and incentives.
- Create policies to favour bamboo biomass based power generation

Incense sticks

8.11 Miscellaneous uses:

Safety matches and agarabatti sticks are widely used by all sections of the Indian society. Safety matches industry in India is spread into three categories: the mechanized large scale sector, the hand-made small scale and cottage sector. Match boxes containing 50 match sticks, account for 92 per cent of the Indian market. Generally wood from semul, kadam and poplar are used for this purpose. But some of these woody species take generally between 10 and 30 years to yield wood of suitable size and requirement and the demand for suitable wood material is always high. Match stick manufacturing activity is concentrated in places like Sivakasi, Kovilpatti and Gudiattam in Tamil Nadu and its marketing is highly organized. Around 82 per cent of total match stick production in the country is in the handmade (small scale 67 per cent and cottage 15 per cent) sector, where technology has remained relatively simple, providing employment for approx. 250,000 people. Simple hand operated machines also are available for manufacturing agarabatti sticks.

With NMBA support, community level manufacturing facilities including bamboo stick making, rolling, adding fragrance packaging/branding have been developed at Imphal (Manipur), Agartala (Tripura), Jagdalpur (Chhattisgarh), Joypur (Odisha) which provideemployment of more one million man days per annum. The initiative has resulted in larger value addition in stick making areas / regions in terms of stick making, rolling and adding fragrance.

"Bamboo as a building material has the potential to become the solution for Pradhan Mantri Awas Yojana-housing project by 2022, disaster management and for achieving sustainable development goals as per Paris Agreement. For this, policy changes for definition of what is a 'pucca' house, inclusion in schedule of rates, tax benefits for bamboo in housing sector are the other initiatives needed. Getting adequate quantity of seasoned and treated material for construction has been a major impediment in bamboo architecture. Currently, at a centralized location, it is very difficult to source material for meeting needs of construction industry due to lack of warehousing and storage facilities. There is also an equivalent lack of properly trained skilled manpower in bamboo sector, which has compounded the problem"

- Neelam Manjunath, Propritrix, Manasaram Architects, Founder and Managing Trustee, Center for Green Building Materials and Technology (CGBMT), Bangaluru

8.12 Future Strategies

8.12.1 Networking of industries

- A cluster approach, as described in the chapter 'Processing and Value-Addition' (Para 7.9.1) should be adopted for promoting the networking of various industries. This would reduce wastages, promote efficiency and develop expertise in manufacturing process and ultimately result in a significant drop in cost of production.

8.12.2 Raw material supply and product manufacture

- Strategies suggested for primary and secondary processing stage (Para 7.9.2 and 7.9.3) apply to product development stage as well.
- In addition to the above, the production should be focused towards high-value as well as high-volume goods for domestic as well as export market.
- New premium products such as bamboo scrimber, bamboo flooring, laminated furniture, etc. should be produced by the industry. New types of 'pack-flat' and 'knock-down' products ought to be promoted for cheap transport.
- Mechanisation /semi-mechanization should be done in handicraft, agarbatti stick and furniture industries.
- Newer product must also be identified and produced based on regular market surveys from domestic and international markets.

8.12.3 Quality standards/ assurance and branding

- At present, specific quality standards do not exist for bamboo products and, as a result, the potential customer is not assured of the quality of the product. A specialised agency should be entrusted with the task of developing such standards. Product testing and quality control must be enforced.
- Big retail chains can be roped in to promote sale of bamboo-products to high- and middle-income groups in urban centres.

8.12.4 Increasing scope of bamboo use

- Armed forces and para-military should be called upon to benefit from innovative bamboo products, especially 'pack-flat' and 'knock-down' pre-fabricated houses which can be dismantled and easily transported. Such housing units can save a lot of cost on material and transport.
- Bamboo bridges in remote areas may be popularised for rural populace as well as for the armed forces, as these are cost-effective and can be constructed at a very short notice.
- Organizations such as DRDO, IPIRTI and ICFRE must collaborate to develop strategic products for defence needs. A policy directive in this regard by the Government is most essential.

8.12.5 Warehousing

- Absence of proper grading and storage facilities hamper procurement of bamboo by industries, often leading to damage and poor quality of harvested stock. Bamboo takes greater time and effort as compared to timber for production and construction components, which makes the products relatively expensive to the consumer. Proper warehousing and storage must, therefore, be essential part of the entire processing and production process. Such facilities, must therefore, be developed at strategic locations.
- Large warehouses of manufacturers should be located closer to consumption centres (domestic market and sea ports) for speedy supply of products in domestic and overseas markets at lower cost

  Online marketing of bamboo products should be promoted as it reduces the warehousing

8.12.6 Tax relief

- Tax relief must be provided to industries manufacturing finished products on the guiding principles of semi-processed products (Para 7.9.7).

8.12.7 Exim policies

- Finished bamboo product should also be provided a favourable import-export policy regime on the lines of semi-processed product (Para 7.9.8).

8.12.8 Robust market mechanisms

- Strategies for primary and secondary processing (Para 7.9.9) may be extended to final product manufacturing stage as well.

8.12.9 Infrastructure

- Uninterrupted supply of water, chemicals, electricity, and suitable good transport and communication services, that are required for primary and secondary processing, may be provided to finished product manufacturers also.

8.12.10 Stakeholder linkages

- Finished product manufacturers must be included in the stakeholder network as an essential component

8.12.11 **Appropriate technologies**

- Research and development should be geared up to provide technological backup to the product manufacturing process; the approach suggested for primary and secondary processing (Para 7.9.4) would apply to manufacturing also.

8.12.12 Capacity and skill development

- Strategies mentioned under the chapter 'Processing and Value-Addition' (Para 7.9.10) apply to this chapter too.

CHAPTER - 9

INSECT PEST AND DISEASE MANAGEMENT

9.1 Introduction

Forest vegetation, including bamboos, provides food and breeding sites for many insect species and diseases. In general, pests and diseases are more numerous in the tropics than temperate forests. Insects, as a group, are capable of feeding on almost all parts of bamboo - the leaf, shoot, culm, rhizome, root and the seed. Similarly, diseases like leaf spot, leaf blight and seedling wilt affect the bamboo in nurseries, while bamboo mosaic disease, witches' broom, little leaf disease and emerging culm rot affect the bamboos in plantations. Combined impact of these pests and diseases can be significant, sometimes accounting for heavy resource losses and pest management costs (Ciesla, 2011).

9.2 Insect Pests on Growing Plant

About 200 species of insects belonging to orders Coleoptera, Hemiptera, Isoptera, Lepidoptera and Thysanoptera are reported to be associated with various species of bamboo in India and the adjoining countries (Bhasin *et al.*, 1958; Mathur and Singh, 1959; Singh and Bhandari, 1988; Thakur, 1988; Mathew and Varma, 1990; Singh, 1990). Muthukrishnan *et al.* (2009) enlisted 65 species of insects occurring on bamboos under storage. Twenty species of insect pests have been reported from cultivated bamboos in Karnataka (Remadevi *et al.*, 2011). Many of the pests are controlled by natural enemies including parasites and predators (Revathi and Remadevi, 2011). Pushpa *et al.* (2012) reported nine species of whiteflies breeding on bamboo in India.

Fig. 9.1: Sucking pests: aphids (A-C); whiteflies (D). (Photo credit: R. Raja Rishi, IWST)

The diversity of insect pests feeding on bamboo is reflected in their feeding habits. According to their food habits, these insects can be grouped into sap suckers (Fig.9.1), defoliators, (Fig. 9.2), shoot/culm borers (Fig. 9.3 and 9.4), rhizome feeders (Fig. 9.5), seed feeders and dry or dead bamboo feeders which (Fig. 9.6) are mainly termites.

(a) Aphids: Among sucking insects, aphids were major pests on bamboo species damaging the sap from lower surface of leaves. They damage bamboo by sucking the sap, causing stunting of growth, deformation of leaves. Besides these, Aphids also transmit many viruses. Aphid species of *Oregma bambusa* is reported infesting *Bambusa tulda*, which cause the young shoots to wilt and die (Chatterjee and Sabastian, 1966). Ghosh (1980) has reported about 15 species of aphids attacking bamboo in eastern India.

Pests of harvested bamboo

Dinoderus minutus
D. ocellaris
D. brevis
Heterobostrychus aequlis
Lyctus africanus
L. brunneus
Minthea rugicollis

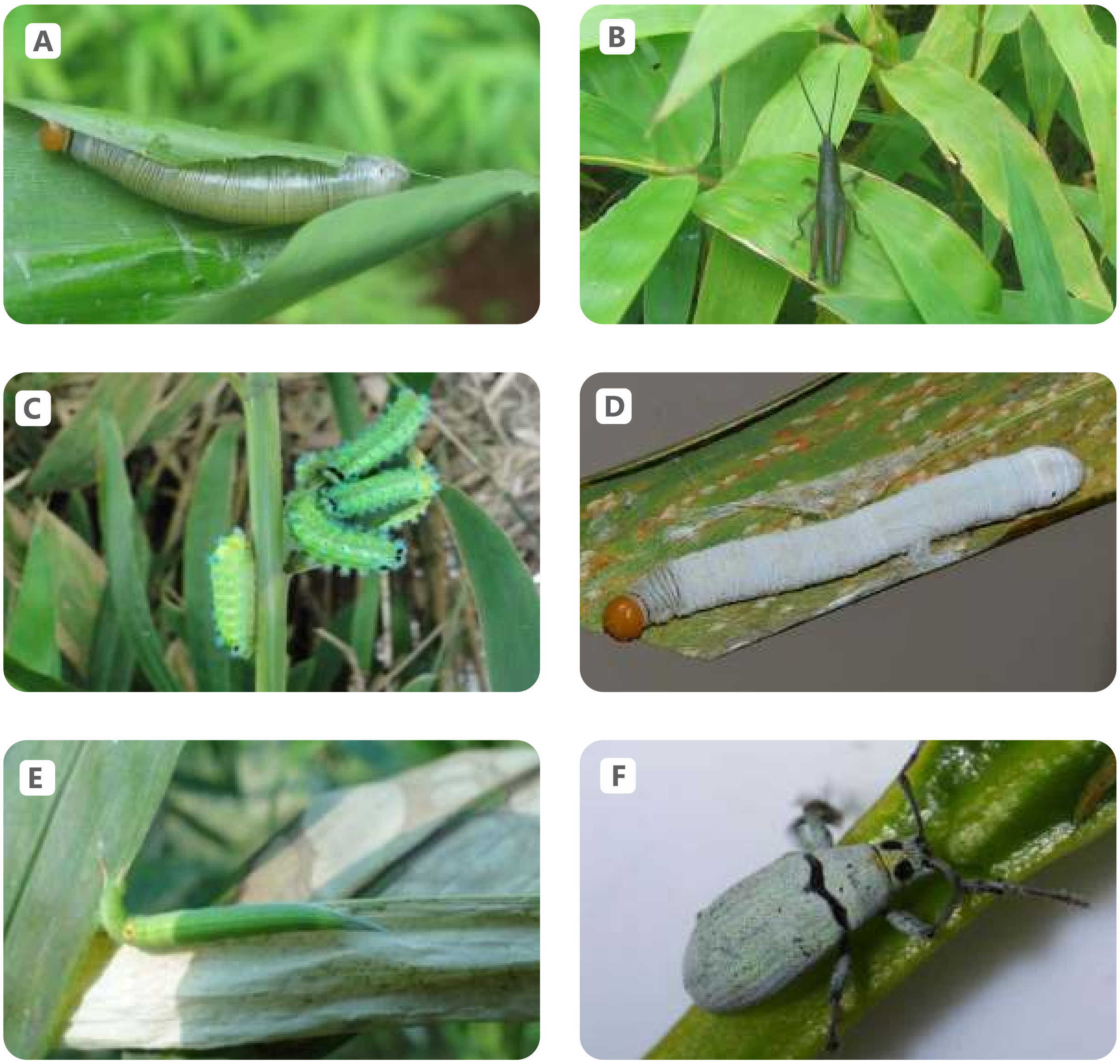


Fig. 9.2: Major defoliators (A-F)

(b) Bugs: The bamboo bug, *Notobitus meleagris* causes the death of plant cells and necrosis as a result of injection of its toxic saliva into bamboo shoot while feeding. The distribution of bug is limited to India, Taiwan and southern China. The pentatomid bug, *Udonga montana,* feeds on the developing seeds of bamboos and a very heavy build up of this bug is noticed periodically in bamboo forests coincident with gregarious bamboo flowering. *Estigmena chinensis* is the most important pest of standing bamboos in natural forests and plantations. Sometimes, 100 per cent culms in a clump are attacked. The lesser leaf roller of bamboo, Defoliaters like *Pyrausta bambucivora* causes injury in bamboo forests of northwest Himalaya particularly in moist nullahs, while *P. coclesalis* is a common defoliator of bamboo in Indian subcontinent. Bamboo weevils, *viz.*, *Cyrtotrachelus dux, C. longimanus. Dinoderus ocellaris, D. minutus* and *D. breviscan* cause immense damage in felled bamboos they attack when bamboos are in the process of drying.

Borer insects like *Purohita cervina* reduce the structural integrity of bamboo and also kill the growing portion of trees and cause growth reduction and tree deformity. Other economically important group is defoliators and leaf rollers and their feeding is manifested as defoliation of bamboo in nurseries and plantations. Dry/dead bamboo feeders are mainly termites and they cause considerable destruction to bamboo nurseries, plantations and natural forests.

Fig. 9.3: Shoot borer and symptom of its infestation (A-B)

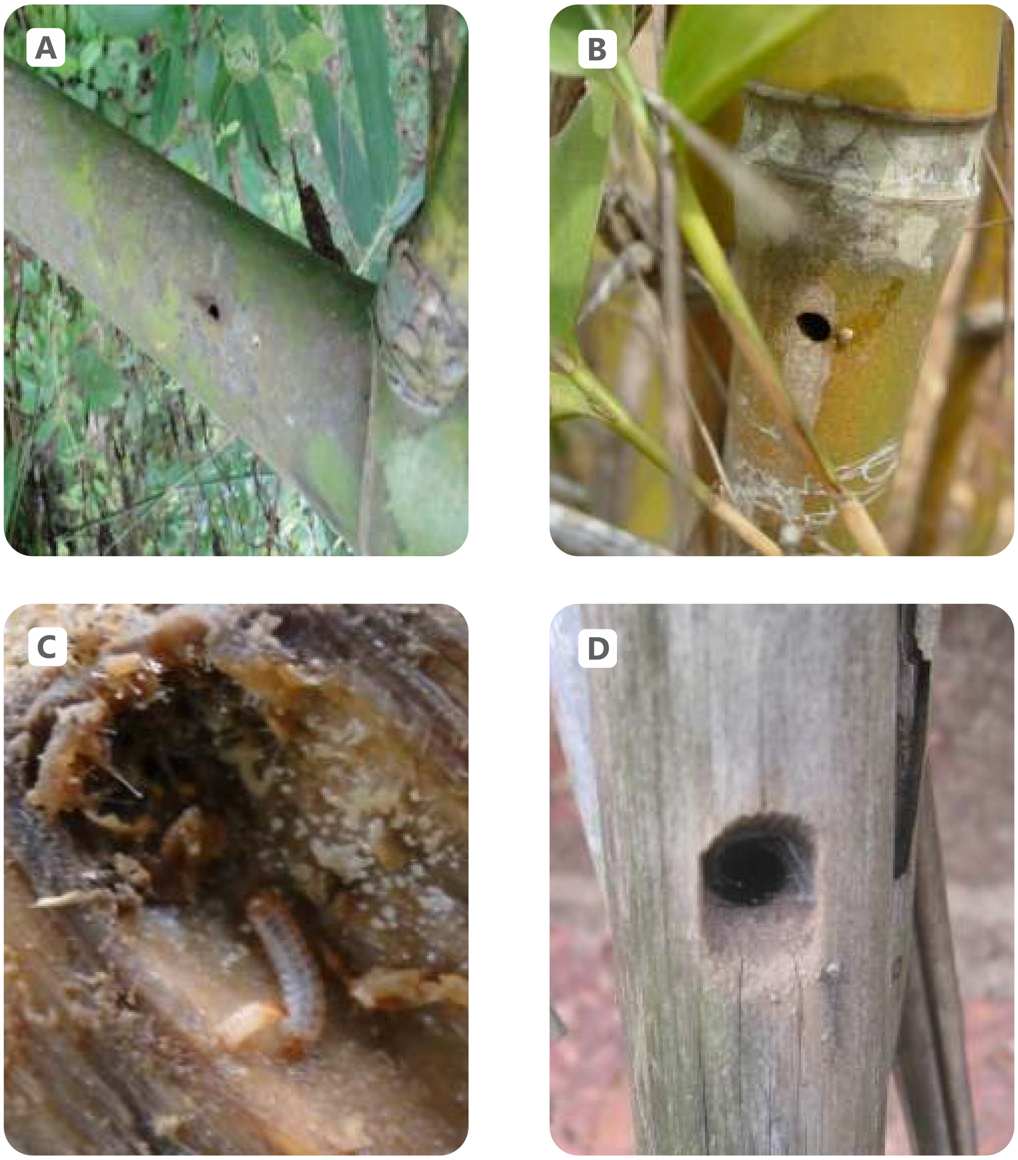


Fig. 9.4: Culm borer infestation and symptoms of infestation in different stages of growth (A-D) (Photo credit: R. Raja Rishi, IWST)

Fig. 9.5: Root grub beetles (A) and light trap used for collection of adult beetles (B)

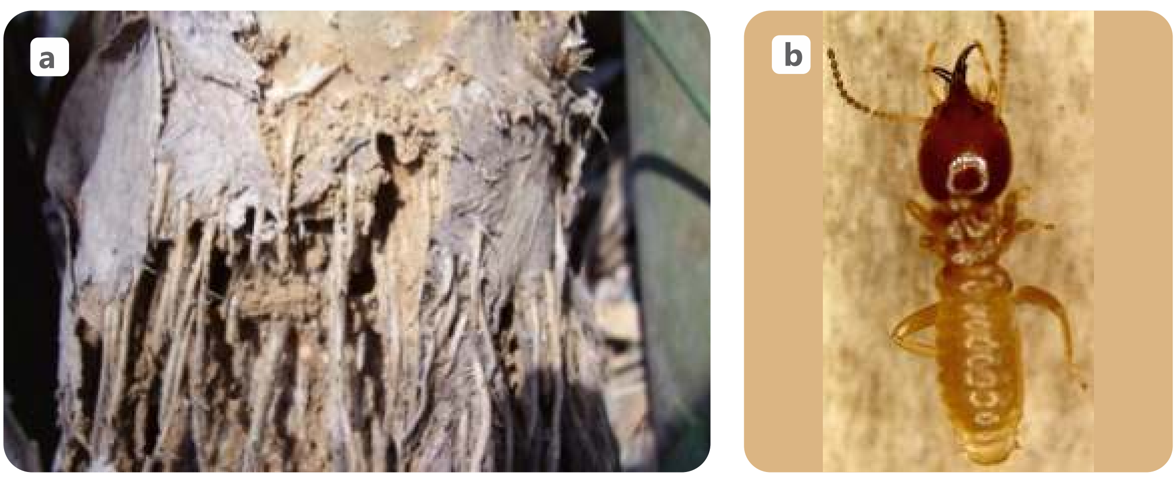


Fig. 9.6: (a) Symptom of termite damage and (b) the common species of termite

9.3 Insect Pests during Storage

Of the various insects attacking harvested bamboo, the Bostrychid and Lyctid borers are the most important. *Dinoderus minutus, D. ocellaris, D. brevis* and *Heterobostrychus aequlis* belonging to Bostrychidae as well as *Lyctus africanus, L. brunneus* and *Minthea rugicollis* (Fig. 9.7) belonging to Lyctidae are the important post harvest pests in India. Infestation of both adults and larvae of these insects reduce a stack of bamboos into a powdery mass of frass within a few weeks.

D. minutus | Cross section of bamboo showing damage by *Dinoderus* beetles. | *L. africanus* | *M. rugicollis*

Fig. 9.7: Some important powder-post beetles attacking bamboo

8.4 Integrated Insect Pest Management on Bamboo

Pest problem is one of the major constraints for achieving higher production in bamboos. FAO (2007) commented that a large number of insects and diseases are known to damage both naturally regenerating forests and plantations in India although little statistics are available on the area affected by these insects. In tropical forests serious pest attack is exceptional but most tree species and bamboos in plantations are attacked by one or more serious pests. Pesticides or chemicals are generally used to control harmful pests such as insects, nematodes, diseases, weeds etc. But their use is undesirable when bamboo is used for food, medicines, utensils, etc., The concept of integrated pest management (IPM) exploits all the available options so that the insecticide load to the environment can be minimized. The IPM practices are to be adopted for raising nurseries, seed sowing, bed preparation etc. but most of the control operation is limited to the nursery stage in the form of chemical inputs. The details of major insect pests of bamboos are grouped based on their feeding habits and their possible management practices is listed in Table 9.1.

Table 9.1: Feeding habit of insects on bamboo in nurseries and plantations and suggested IPM practices

S. No.	Type	Symptom of damage	Insect pest species	Possible integrated pest management practices
1.	Sap suckers	• These insects have highly modified piercing-sucking mouth parts; they suck the sap from phloem or xylem of leaves, branches, culms, shoots, roots and rhizomes. These insects can damage bamboo in four ways: ○ removing the plant fluid, ○ causing mechanical injury from egg-laying, ○ injecting toxic compounds, into the plant, and ○ transmitting diseases. The results are defoliation, wilting of young shoots and branches and even death of the culm.	*Astegopteryx bambusae* *Astegopteryx formosana* *Chrysocoris purpureus* *Coptosoma feanum* *Erthesina fullo* *Hysteroneura setariae* *Melanaphis bambusae* *Mukaria* sp. *Notobitus meleagris* *Oregma bambusae* *Ochrophara montana* *Plautia fimbriata* *Pseudoregma bambusicola* *Putala* sp. *Purohita* sp. *Whiteflies*	• Monitoring the incidence of sucking pests is pre-requisite to initiate the management practices. Pruning and burning of infested materials. • Application timing is critical to control them with most insecticides. Sprays are to be timed to coincide with the early stage and preference to be given to less persistent chemicals. Spraying of Monocrotophos (0.02–0.05 per cent), 0.2–0.3 per cent Chlorpyriphos, Quinalphos, Metasystox or Imidacloprid or neem oil at 0.5 per cent at the initial stages can control the pests. • In later stages spraying the affected plants thoroughly with 0.5 per cent Quinalphos along with 0.05% sticker. • Soil drenching primarily with neonicotinoid insecticides (e.g., imidacloprid and thiamethoxam) is highly effective. • Soil application of plant seed cakes and/or carbofuran granules @ 0.75 to 1gm a.i/plant. Preference to be given to systemic insecticides and same chemical should not be used repeatedly.

S. No.		Symptom of damage	Insect pest species	Possible integrated pest management practices
2.	Defoliators	• Feed on leaf material, often remain low in population but some of them show periodic fluctuations in population and epidemics can cause severe or even total defoliation of bamboo stands. Defoliation reduces the surface area available for photosynthesis, affecting vigour, growth and survival of plants.	*Aulacophora* sp. *Brachytrypes portentosus* *Cosmopteryx bambusae* *Cyrtotrachelus dux* *C. longimanus* *Crypsipyta coclesalis* *Eliamaea* sp. *Heliothis armigera* *Hieroglyphus banian* *Matapa aria* *Myllocerus* spp. *Parasa* sp. *P. bambucivora* *Pyrausta coclesalis* *Schistocerca gregaria*	• Spraying of 0.02- 0.05 per cent of Monocrotophos, Quinalphos, Chlorpyriphos or neem formulations as per the recommended dosage. Preference to be given to contact insecticides. For weevil Brigade liquid 5ml/lit spray (Beauveria in Metarrhizium) content.
3.	Rhizome feeders	• Grubs feed on rhizomes	*Holotrichia serrata*	• EPN formulation; aggregation pheromone is Methoxy benzene (Anisole) readily available. suppliers. Light trap also effective (Fig. 9.5).
4.	Shoot/ Culm feeders	• These are considered to be of major economic importance as their infestation can greatly reduce culm and shoot yield. • A single larva of a culm borer can destroy a culm. Also, making way for infestation of secondary insects and pathogens	*Argyroploce (Olethreutes) paragramma* *Estigmena chinensis* *Crytachelus dux* *Estigmena chinensis* *Mecistoscelis scirtetoides* *Purohita cervina*	• Locating the live grub/larvae and killing by inserting stiff iron wire. Pouring jaggery solution in hole of tunnel to attract ants which will later on attack the grub live or dead in the tunnel. Injection of monocrotophos and then sealing with mud also effective. Application of healer cum sealer.

S. No.		Symptom of damage	Insect pest species	Possible integrated pest management practices
1.	Gall inducers	• Galls, induction mainly by chalcid wasp species, • Galls cause abnormal growth and shedding of leaves on the affected twigs and thus, probably, affect photosynthesis	*Chalcid wasp* species	• Not a problem in India
2.	Termites	• Usually, feed only on dying and dead culms; however, the termites feeding around bamboo culms cause new culms to originate higher up, ultimately. A few termites belonging to the genus Odontotermes are reported to cause injury to the root system of resulting in congested culm growth	*Drywood* and *subterranean termites*	• Eradication of termite mounds with suitable insecticides. • Drenching of soil with 1.5 per cent Chlorpyriphos, Cypermethrin, Bifenthrin,
3.	Seed feeders	• Seed pests, which affect seed production, have some impact on the establishment of new plantations	*Udonga montana* *Sitotroga cereallela*	• Fumigating seeds with carbon disulphide. Methyl bromide can also be used, but it is an ozone depleting chemical, the use of which is being phased out. • 100 kg of seeds can be fumigated with 2-3 ml of fumigant

9.5 Fungal and Bacterial Diseases

9.5.1 Grown bamboo

Diseases and pathogens of bamboo in nurseries and natural stands in India were studied by Mohanan (1990, 1994 a,b,c,& 2002), Mundkur and Kheswala (1943), Ananthanarayan (1994), Awati and Kulkarni (1972), Singh and Pandey (1971), Bakshi *et al*. (1972), Harsh *et al*. (1989), and Balakrishnan *et al*. (1990) in Table 9.2 and Table 9.3. A database has been compiled highlighting the common fungal diseases of different bamboo species in India which are important from economical and ecological point of view. (Figs. 9.8 & 9.9) present some common diseases of bamboo.

Table 9.2: Diseases and pathogens of bamboo in nurseries

S. No.	Disease	Pathogen	Bamboo species affected
1.	Damping-off	*Rhizoctonia solani* *Fusarium moniliforme* *F. oxysporum*	*B. bambos, D. strictus, D. brandisii, T. siamensis*
2.	Seedling spear rot	*R. solani*	*B. bambos, D. strictus*
3.	Seedling wilt	*R. solani*	*B. bambos, D. strictus*
4.	Web blight	*R. solani*	*B. bambos, D. brandisii, D. strictus, T. siamensis, B. blumeana*
5.	Leaf rust	*Dasturella divina*	*B. bambos, D. brandisii, D. strictus, T. siamensis, B. blumeana, O. travancorica, O. scriptoria, Phyllostachys ritcheyi*
6.	Bipolaris leaf rust	*Bipolaris maydis, B. urochloae, B. bambusae*	*B. bambos, D. brandisii, D. strictus, T. siamensis, D. membranaceus, O. wightii, T. pubescens*
7.	Exherohilum leaf spot	*Exherohilum rostratum, E. holmii, E. halodes*	*B. bambos, D. strictus, P. pubescens,*
8.	Dactylaria leaf spot	*Dactylaria bambusina*	*B. bambos, D. brandisii, D. strictus, T. siamensis, O. wightii*
9.	Colletotrichum leaf spot	*Colletotrichum gloeosporoides*	*B. bambos, D. strictus, B. blumeana*
10.	Curvularia leaf spot	*Curvularia pallescens*	*B. bambos, B. vulgaris, D. longispathus, O. scriptoria, T. oliveri*
11.	Alternaria leaf tip blight	*Alternaria alternata*	*B. bambos, D. strictus*
12.	Seedling rhizome rot	*Rhizostilbella hibisci*	*B. bambos*

Table 9.3: Diseases and pathogens of bamboo in natural stands

S. No.	Disease	Pathogen	Bamboo species affected
1.	Rot of emerging culm	*Fusarium moniliforme var. intermedium* *Rhizoctonia* sp.	*B. bambos, B. balcooa, B. polymorpha, B. vulgaris, D. strictus, D. longispathus, T. oliveri* *D. strictus, O. travancorica, O. scriptoria*
2.	Rot of growing culm	*Fusarium equiseti*	*B. bambos, B. balcooa, B. polymorpha, B. brandisii, D. strictus, D. longispathus, T. oliveri*
3.	Bamboo blight	*Sarocladium oryzae*	*B. nutans*
4.	Branch die-back	*Fusarium pallidoroseum*	*B. bambos, B. vulgaris*
5.	Witches'-broom	*Balansia linearis* *Unknown etiology*	*O. travancorica, O. scriptoria, O. ebracteata D. strictus*
6.	Little leaf	*Phytoplasma*	*D. strictus*
7.	Thread blight	*Botryobasidium salmonicolor* *Corticium koleroga*	*B. bambos, B. balcooa, B. polymorpha, B. vulgaris* *D. strictus, Ochlandra.* sp.
8.	Necrosis of culm internode	*Curvularia lunata*	*Thyrsostachys oliveri*
9.	Culm smut	*Ustilago shiraiana*	*Phyllostachys sp., Bambusa* sp.
10.	Culm staining and die-back	*Apiospora*	*B. vulgaris, D. longispathus*
11.	Sooty stripe	*Papularia arundinis*	*Bambusa* sp.
12.	Culm stain	*Apiospora indica* *Aspergillus* sp. *Capnodium* sp. *Geotrichum* sp. *Penicilliopsis bambusae* *Periconia cookei* *Trichoderma* sp.	*Bambusa* sp. *Bambusa* sp. *B. bambos, D. strictus* *Bambusa* sp. *Bambusa* sp. *Bambusa* sp. *Bambusa* sp.
13.	Foliage blight	*Bipolaris bambusae,* *B. maydis*	*B. bambos, B. polymorpha, B. brandisii, D. longispathus, D. strictus, P. ritcheyi*
14.	Dasturella leaf rust	*Dasturella divina* *Dasturella bambusina*	*B. bambos, B. balcooa, B. multiplex, B. tuldoides, B. vulgaris, D. brandisii, D. hamiltonii, D. longispathus, D. strictus, P. ritcheyi, O. travancorica, O. scriptoria, T. siamensis, T. oliverii* *Bambusa* sp.
15.	Puccinia leaf rust	*Puccinia gracilenta* *P. melanocephala* *P. xanthosperma*	*Bambusa* sp. *Arundinaria* sp., *Bambusa* sp. *Bambusa* sp.
16.	Uredo leaf rust	*Uredo bambusae-nanae*	*B. nana*

17.	Tunicospora foliage rust	*Tunicospora bagchii*	*D. strictus*
18.	Zonate leaf spot	*Dactylaria bambusina*	*B. bambos, B. polymorpha, D. longispathus, D. strictus, O. ebracteata, O. travancorica, O. scriptoria, Thyrsostachys* sp., *T. siamensis*
19.	Ascochyta leaf spot	*Ascochyta arundinariae* *A. bambusinae* *A. dendocalami* *A. phaseolorum*	*Drepanostachyum falcatum* *A. multiplex* *A. bambos, D. strictus, T. siamensis* *A. bambos,*
20.	Tar spot	*Phyllachora bambusae* *P. dendrocalamii* *P. graminis* *P. longinaviculata*	*B. bambos, Bambusa* sp. *D. strictus* *Arundinaria sp., Phyllostachys* sp. *B. bambos, D. strictus, P. ritcheyi*
21.	Petrakomyces leaf spot	*Petrakomyces bambusae* *P. indicus*	*Thyrsostachys* sp. *Arundinaria* sp., *B. bambos, D. strictus, O. ebracteata, O. scriptoria*
22.	Phoma leaf spot	*Phoma dendrocalami* *P. herbarum*	*D. strictus, B. bambos* *D. strictus, B. bambos*
23.	Phomopsis leaf spot	*Phomopsis bambusae*	*B. bambos, D. strictus, Thyrsostachys sp.*
24.	Stagonospora leaf spot	*Stagonospora bambusae*	*B. bambos, D. strictus*
25.	Septoria leaf spot	*Septoria thyrsostachydis*	*Thyrsostachys* sp.
26.	Chaetomium leaf spot	*Chaetomium cameum*	*B. bambos*
27.	Curvularia leaf spot	*Curvularia lunata*	*Arundinaria sp., B. bambos, Thyrsostachys* sp., *O. ebracteata, O. scriptoria, O. travancorica*
28.	Alternaria leaf spot	*Alternaria alternata*	*Bambusa sp., B. bambos, D. strictus*
29.	Coccodiella leaf spot	*Coccodiella ochlandrae*	*O. travancorica*
30.	Cerodothis leaf spot	*Cerodothis aurea*	*B. bambos, D. strictus, Thyrsostachys* sp.
31.	Brown leaf spot	*Fusarium pallidoroseum* *F. semitectum*	*Melocannaarundina, S. dullooa, B. bambos, B. vulgaris, D. strictus, P. ritcheyi*
32.	Culm sheath spot	*Sarocladium* sp.	*B. vulgaris, D. brandisii, D. strictus*
33.	Culm and sheath blight	*Sarocladium oryzae*	*Bambusa* sp.
34.	Black mildew	*Meliola bambusicola* *Asterinella hiugensis*	*Bambusa sp., O. travancorica, O. ebracteata, O. scriptoria, B. multiplex, B. vulgaris* *Bambusa* sp.
35.	Sooty mould	*Capnodium* sp. *Spiropess copiformis*	*B. bambos, B. vulgaris, D. strictus, D. longispathus, Ochlandra spp.* *B. bambos, B. vulgaris, D. strictus, O. travancorica, O. ebracteata*

36.	Rhizome bud rot	*Pythium middletoni*	*B. bambos*
37.	Rhizome and root rot	*Amylosporus campbelli*	*B. bambos, D. strictus, T. oliveri*
38.	Decay of rhizome, root and basal cul	*Ganoderma lucidium*	*B. bambos, T. oliveri, M. baccifera, Bambusa* sp.
		Polyporus bambusicola	*B. bambos*
		Poriarhizo morpha	*M. baccifera*
39.	Culm rot	*Pterulicium xylogenum*	*B. vulgaris, Dendrocalamus* sp. (Harsh *et al.*, 2005)

(Source (except S. No. 39): Diseases of bamboos in Asia: An illustrated manual by C. Mohanan, Kerala Forest Research Institute, Peechi)

9.5.2 Stored bamboo

In India, the decay fungi (Fig. 9.10) recorded on stored bamboos are (*Rigidoporus lineatus (=Polyporus zonalis), P. tenuiculus, P. grammocephalus, Polystictus steinheilianus, Oxyporus cervino-gilvus (= Poria diversispora), Poria rhizomorpha, Pleurotus sp., Lenzites elegans, Nigroporus durus (=Fomes durus), Fomes hypoplastus, Schizophyllum commune, Stilbum erythrocephalum, S. lateritium, Tetraploa aristata, Thelephora palmata, Earliella scabrosa (=Trametes persoonii), Tremella fuciformis, Gloeophyllum striatum, Cyathus limbatus, Sphaerostilbe bambusae, Sporidesmium nilgirense, S. leptospermum, Cribariain tricata, Flammula dilepsis, Apiospora montagnei, Lacellina graminicola, Phellinus gilvus, Coriolopsis telfarii, Datronia caperata, Flavodon flavus, Lenzites acuta, Polyporus arcularius,* etc. (Mathur, 1936; Patel *et al.*, 1949; Banerjee and Ghosh, 1942; Subramaniam, 1956; Bakshi *et al.*, 1963; Kar and Maity, 1971; Mohanan, 1994; Harsh and Kapse, 1999))

(A) Rot of growing culm

(B) Rot of emerging culm

(C) Leaf rust

(D) Root rot

Fig. 9.8: Common diseases of bamboo (A to D)

(A) Culm stain

(B) Culm decay

(C) Sheath and culm blight

Fig. 9.9: Common diseases attacking bamboo culm (A-C)

Fig. 9.10: Fungal decay on dried bamboo (A) and in storage (B)

9.5.1 Traditional methods of pests and disease management

- The borer incidence has strong correlation with the amount of nutrients available in felled culms which vary significantly with the bamboo species, growing sites, culm age, felling season and the mode of transport. Considering these aspects, some preventive measures have been available against these borers.
- Harvesting of 3-4 year old culms and felling at winter or rainy season are generally recommended.
- Mathur (1961) reported clump curing which involves cutting the culms at the base and leaving them vertically leaning against other culms in the clump for 4 weeks to bring down the starch level.
- Heating of culms in fire or boiling water, smocking, burying the culms in beach sand, curing in sea water or application of slaked lime.
- Submersion in water and curing in the clump are reported to decrease the starch content stored in culms tissues. Immersion in water for 4-12 weeks leads to leaching out of soluble materials in the culms that make it unacceptable to borers (Fig. 8.11).
- In Bangladesh, a method of mud curing is practiced in which freshly cut culms are soaked in muddy pond for 1-8 weeks and then slowly dried in the shade (Chowdhury, 1993). Treating the culms in boiling water for 15-60 minutes is reported to be effective in leaching out starch.
- In China, treating bamboo infested with *D. japonicus* under high pressure steam (5 lb at 108° C for 10 minutes) or soaking in hot water was effective in controlling the beetle. In Japan, the culms are smoked at 50-60ºC usually using the leaves of felled bamboo.
- Smoking is believed to deposit toxic substances and destroy the starch in the culm tissue and thus offering resistance to degradation (Hidalgo, 2003). Prior to smoking, the culms are perforated in such a way that the holes are scattered and not in a line. Heating the culms in open fire or in special heating chambers can also be carried out (http://www.trada.co.uk/-).
- Momentary exposure of culms to temperature as high as 150° C has been suggested, but there is a risk of culms splitting due to heat.
- Decay and bio-deterioration of bamboo culms during outdoor storage can be control by adopting good storage and management practices. Culms should be stacked horizontally over raised walls to facilitate water drainage and proper air circulation. For reed bamboos, vertical stacking results in a small gain in pulp yield over horizontal stacking because the former suffers less fungal damage.

9.5.2 Chemical treatments

An exhaustive review on bamboo preservation techniques has been made by Kumar *et al.* (1994) on behalf of INBAR. Basically, there are two methods for increasing the durability of bamboos: (1) non-chemical method (non-preservative) and (2) chemical method. Bamboos used for structural purposes are often treated by non-chemical or traditional method, although not much is known about their real effectiveness. However, the treatment is less expensive and can be carried out at village level without the use of special equipments. These methods include curing, smoking, lime-washing and soaking. (Martawidjaja, 1986; Singh and Nigam, 1968; Kumar *et al*., 1980 & 1983; Liese, 1993; Gnanaharan *et al.*, 1993). Bamboo culms are treated during or immediately after extraction and before stacking in the storage yard. Harvested culms with branches and leaves intact are left in open air in curing. Smoking bamboo culms over fire is another traditional method which is considered as an effective treatment against insects and fungi. Painting of culm with lime is widely used and said to ward off fungal attack. Often, culms are painted with a mixture of tar and sand, or plaster, cow dung and lime, to prevent fungal and insect attacks. Another method is to submerge the culms in either stagnant or running water, or mud for several weeks.

Chemical protection ensures a longer life for bamboos. Culms can be treated using a variety of chemicals, depending upon the culm condition (green or dry) and also on their end use. Various chemical treatments recommended for increasing the service life of fresh (green) bamboo include: steeping, sap displacement, diffusion process and boucherie process. Treatments for dry bamboo culms include soaking in a preservative solution, hot-cold process and pressure treatment. Methods that use preservative chemicals are generally more effective than non-chemical methods in the protection of bamboo under storage, but they are not always economical or feasible. Gnanaharan *et al*. (1993) suggested that reed bamboos used for mat weaving can be stored effectively even up to 8 months by keeping them under water (running or stagnant), or a disinfectant solution (bleaching powder or potassium permanganate) or preservative chemical solution (copper sulphate or boric acid) of very low concentration. Chemical treatment on a large scale is performed mainly in India, Japan and China. Prophylactic chemical treatment at the time of stacking and after 4-6 months is recommended for protecting structural bamboo culms stored outdoors (Kumar *et al*., 1990, 1994). Chemical preservatives recommended against fungal and insect attacks are invariably toxic to mammals. Slight carelessness in the use of such chemicals can endanger the safety of those handling the chemicals and freshly treated bamboo.

- Application of various preservatives, repellents and pesticides has been tried for bamboo protection. Traditional chemical methods (Fig. 9.11) of treatments are mostly intended to ward off the insects either due to repellent or toxic nature of the chemicals used. Slaked lime, mud, cow dung, motor oil, diesel, kerosene, varnish, tar dissolved in wax, naphthalene, formalin, etc., have been used to prevent borer infestation. Various pesticides have been tried in the past to control bamboo borers. Some commonly reported methods are given below:
- Use of commercial formulations of insecticides like pyrethroids - cypermethrin and permethrin were found effective (Varma *et al*., 1988).
- Semi finished bamboo products can be treated by soaking in 2 per cent aqueous solution of boric acid, 0.5 per cent pentachlorophenate and 5 per cent alcohol (Haojie *et al*., 1998).
- Prothiophos and phoxim- two low-toxicity organophosphides, were more effective than organochlorine ones for preservation of bamboo materials (Mori and Hideo, 1979).
- Treating bamboo splits by immersing in 0.2 per cent phoxim for three minutes can result in total mortality of Dinoderus beetles present inside and will afford protection for nearly one year (Zhou Huiming, 1987).
- Soaking in an aqueous solution of methamidophos or 0.033-0.001 per cent trichlorphon (Dipterex) for 8 hours is recommended for controlling *D. japonicus* in China (Chang Lefeng *et al*., 1979).
- Application of neem oil or Cypermethrin 0.4 per cent in diesel oil at the cut ends and on the surface has been reported to be effective.
- Chemical treatments using various wood preservatives have also been recommended.

Soaking bamboo culms in water to leach out starch

Culms stacked in a heating chamber

Culms being preparedfor chemical treatment in the boucherie method

Filling the culms with preservative chemical in the boucherie method

Wood preservative treatment tank

Vacuum pressure impregnation unit

Fig. 9.11: Various methods of wood preservation (Courtesy; Geroge Mathew, KFRI)

Preservative chemicals recommended

a) Coal tar creosote and fuel oil (50:50) by weight. Coal tar creosote should meet the relevant standard specification for preservation purposes (Anonymous, 1961),

b) Copper-chrome-arsenic composition containing copper sulphate, sodium or potassium dichromate and arsenic pentoxide in the proportion of 3:4:1 (Anonymous, 198lb),

c) Borated-copper-chrome-arsenic (SBOR) composition conforming to the composition (patent pending) pre- scribed by the Forest Research Institute, Dehradun,

d) Acid-copper-chrome composition containing copper sulphate 50 parts, sodium dichromate 47.5 parts, chromic acid 1.68 parts (equivalent to 2.5 parts of sodium dichromate) (Anonymous, 1981a),

e) Copper-chrome-boron composition containing boric acid, copper sulphate and sodium or potassium dichromate in the proportion of 1.5:3:4 (Anonymous, 198lc),

f) Ammoniacal copper-arsenite composition containing copper sulphate, arsenic trioxide dissolved in ammonia (Dev *et al*., 1991),

g) Boric acid: borax in 1:1.54 proportions,

h) Copper naphthenate/ abietate and zinc naphthenate/abietate containing 0.5 per cent copper or l per cent zinc,

i) Sodium pentachlorophenate, boric acid and borax in 5:1:1 proportion (2.5 per cent solution) for prophylactic treatment,

j) Copper-chrome-arsenic composition, containing copper sulphate, sodium or potassium dichromate, and sodium pentachlorophenate in 2:0.5 proportion (2.5 per cent solution) for prophylactic treatment,

k) DP (2, 5-chloro-3-bromophenol) 0.l per cent solution for prophylactic treatment and

l) In the boucherie method, the preservative chemical is pumped into the culms. For this, the septa of culm segments (except the last septum) are pierced with a long, pointed iron rod and the preservative is pumped into the cavity (http://www.guaduabamboo.com). The treated poles are stacked vertically for 7-8 days after which they are allowed to get dried in the open. Usually, 2-3 per cent solution of borax: boric acid in 5:1 ratio is used for treatment. Bamboo can be treated by immersing in the treatment solutions kept in a treatment tank under normal temperature. For efficient uptake of the preservatives, the solutions may be heated or treatment carried out under high pressure (Singh and Tewari, 1979). Fumigation of infested material using sulphuryl fluoride at the rate of 30-50 g/cum for 24 hours is also undertaken for protection from borers. Micro-waving and infra red techniques are also in use.

9.5.3 Biological treatment

Biological control agents involve the use of living organism to control pathogens. In this process no chemicals are needed so, there is no environmental contamination of fungicide and the pathogens do not become resistant to the biocontrol agents. Biocontrol agent, *Trichoderma pseudoknoningii* and *T. harzianum* have been tested with encouraging results for the control of decay fungi, *i.e.*, *Datronia caperata, Polyporus arcularis,* and *Schizophyllum commune* on stored bamboos. The bio-control formulation of *T. pseudokoningii conidial* suspension was effective in controlling the fungal decay and found better than chemical treatment with boric acid and borax (Harsh, 2008).

9.5.4 Management of termite infestation

Termites are also often a serious threat to stored bamboo and bamboo products. Both subterranean termites and dry wood termites infest bamboos Adoption of preventive measures such as storing bamboo on raised platforms without touching the soil and carrying out prophylactic treatment is essential to avoid termite infestation. Various termiticides such as Chlorpyriphos (15-20 per cent), Imdachloropride (Premise 30.50 SC) 5 ml/lit or Metarhizium suspension are available to prevent termite infestation. Various ready-to-use oil-based formulations such as 'Wood Guard, Terminator' are available for direct application on borer infested bamboo products.

9.6 Best Practices of Integrated Pest and Disease Management

Many insect pests and diseases on bamboo are economically important as their incidence conflicts with human welfare and profits. Therefore, outbreak of such pests and diseases quiet often becomes a major concern of the foresters and the farmers. The outbreaks are governed by their innate capacity to increase as influenced by various abiotic and biotic factors. Best cultural practices are most important method of preventing pests and diseases. Providing good growing conditions with appropriate watering and bio-fertilisers help the bamboo to be more resistant to pest and diseases. Clean cultivation with disease free seeds and seedlings eliminates the source of infection. Pruning off heavily infested twigs and branches and burn them to eliminate many scales and mealybugs. Application of Panchagavya to young plants improves the resistance against many pests and diseases. Application of neem based pesticides and microbial pesticides to target pests and diseases have an added advantage of eco-friendliness. Conservation and augmentation of the natural enemies and also selection of natural enemy combinations in which the pathogens function as synergist to keep the pests to the level where there won't be any economic loss. Similarly effective implementation of prophylactic treatments for bamboos in storage should be followed.

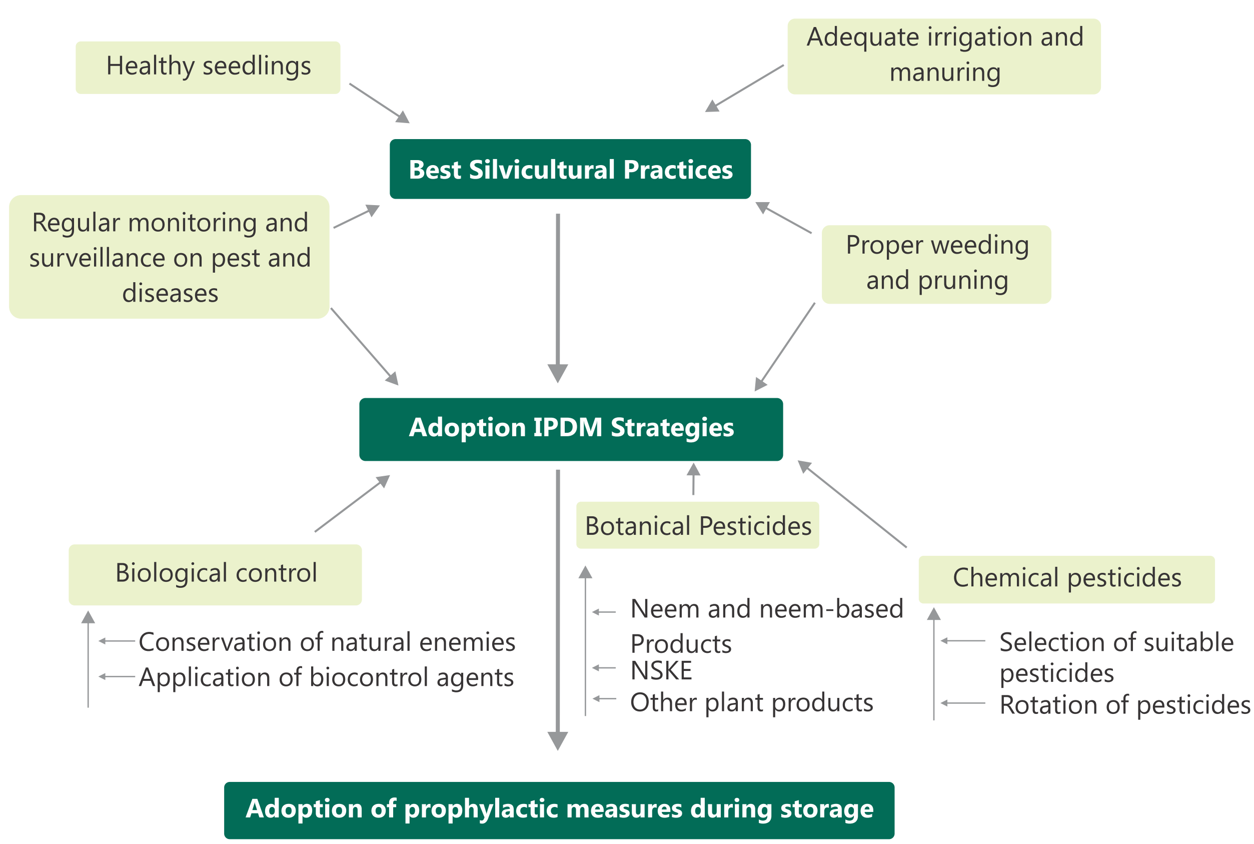


Fig. 9.12: Integrated pest and disease management strategies

9.7 Capacity Building

Since bamboo grows fast, if it is managed well, its high productivity makes it a crop of substantial economic value, especially in rural areas of India. There is also a rapidly expanding market within the country and abroad for bamboo products. Therefore, attempts to improve the productivity of bamboo stands through means such as plantation development and intensive silvicultural measures can be expected to increase in the immediate future. Consequently, it is also prudent to expect that the insect pest and disease problems of standing and stored bamboos will become more significant. Climate change is expected to bring extension in the host range of many pests and diseases. Besides the change in population structure and growth rate among insect species due to global warming will have profound ecological effect by altering species composition and disrupting food webs. However, insect pest and disease problems in bamboo industry have received little attention and the pest status of the many insects and economic damage of many diseases is not fully known.

It is well recognized that the abundance, population dynamics and survival of insect pests as well as incidence of diseases are closely related to various environmental factors. However, there is an abject lack of knowledge on the ecological aspects of bamboo pests. The relationship and interaction among the insect pests and host food quality, natural enemies and physical factors are not known for most of the bamboo pests. Another problem is that most of the control measures recommended for insect pests involve the application of chemical pesticides. Forest field staff and bamboo growing farmers are not having any knowledge on the feeding habits of insect pests and mode of action of insecticides/fungicide which plays an important role in execution of integrated pest and disease management. Hence, it is utmost important to train the field staff and bamboo growers to understand the feeding habits of insects and disease symptoms and thereby selection of suitable safe and effective pesticides to contain them. This will certainly avoid un-necessary usage of pesticides and promote the natural pest and disease control systems. Further long-term, studies on ecological aspects and integrated pest and disease management should be encouraged as such data are essential for the development of effective IPDM strategies. Hence, focus to be given on popularizing and adoption of integrated pest and disease management strategies though monitoring and forecasting of pest build-up and promote biological control and human resource development through on-farm trainings and demonstrations.

Witches' broom on bamboo, Morni Hills Haryana
(Photo : Jagdish Chander, CCF Haryana)

CHAPTER - 10

CLIMATE CHANGE MITIGATION AND OTHER ECOSYSTEM SERVICES

10.1 Introduction

Kyoto Protocol (U.N.) Framework Convention on Climate Change (UNFCCC) has emphasized the role of forest plantations as important sinks of carbon. This development gives the forest plantations a new dimension, which adds to their economic role through the carbon mitigation process as well. Forests are a major sink for carbon and play an important role in the global carbon cycle. Expanding the earth's forests, therefore, may present an opportunity to increase the terrestrial carbon sink, and slow down the increase in atmospheric CO_2 concentration. Both bamboo and palms have significant potential of inclusion under CDM projects, enhance livelihood and food security. Biomass assessment is relatively easy in homogeneous bamboo plantations. Methodologies for bamboo-based carbon mitigation projects have already been developed and accepted in carbon markets.

Due to its biological characteristics and the growth habits, bamboo is not only an ideal economic investment but also has enormous potential for alleviating many environmental problems. Bamboo forest provides environmental services in the form of biodiversity conservation, soil erosion control, water conservation, land rehabilitation and carbon sequestration. Growing bamboo forests and plantations therefore, could be a good idea. Forestation implies increasing the amount of carbon stored in vegetation both above and below ground, dead organic matter and medium and long-term wood products (Watson, 1996). Bamboo also provides many ecosystem services (Table 10.1 and Fig. 10.1):

Table 10.1: Ecosystem services provided by bamboo

Category	Type
Support services	Nutrient cycling, primary production
Provisioning services	Food, fuel, wood, fibre, biochemical, genetic resources
Regulating services	Climate, water regulation and water purification
Cultural services	Spiritual and religious, recreation, aesthetic, inspirational, educational, sense of place, cultural heritage

10.2 Soil Erosion Control

Soil erosion is a major environmental threat to the sustainability and productive capacity of agriculture. It is a worldwide problem approaching disastrous proportions in many countries. Soil is eroded by wind, water, and gravity and exacerbated by tillage and poor soil management. Bamboo is very valuable for controlling soil erosion. It grows well on steep hillsides, road embankments, gullies, or on the banks of ponds and streams. In Hakone-yama mountain of Japan, the bamboo community of Sasa and Indocalamus distributed in the high mountainous area, 1,000 m above the sea level, resulting in little water and soil loss. Brazil introduced *Bambusa blumeana* and *Phyllostachys pubescens* for controlling soil erosion, preventing nutrient loss and improving soil structure (Fu *et al.*, 2000). The valuable features of bamboo for controlling soil erosion are its extensive fibrous root system, connected rhizome system, the leafy mulch it may produce on the soil surface, its comparatively dense foliage which protects against beating rains (Zhou *et al.*, 2005).

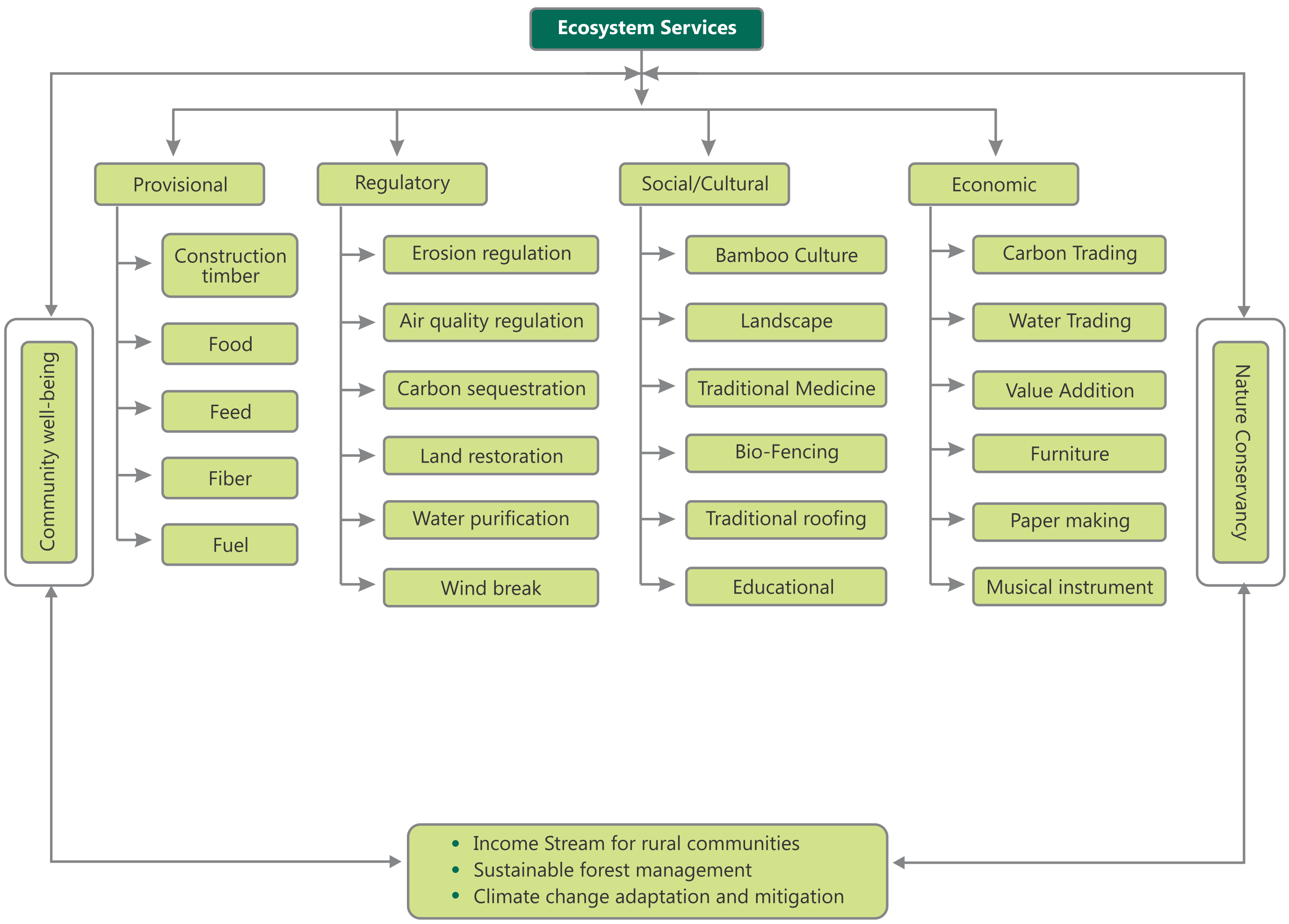


Fig. 10.1: Ecosystem services provided by bamboo (Source : Nath *et al.*, 2009).

10.3 River Banks Protection

Bamboo planted along stream and river banks, grows particularly well because of a more even and abundant supply of moisture. The fibrous mass of roots binds the soft banks, and the thick culms impede strong currents. Bamboos planted in strip form on river banks build a solid wall of living plant material and solve the bank erosion problem forever. Two such cases are reported from China by an INBAR sponsored study where bamboo succeeded in protecting river banks after soil rock engineering efforts and planting of other trees failed to yield results (Anon., 1997)

10.4 Rainfall Interception

Bamboo has evergreen leaves, dense canopy and numeral culms, which can help to intercept considerable amount of rainfall. Falling raindrops change their direction and ways, and reduce velocity, and therefore, decreases its direct soil erosion after multiple interception by tens of shoot layers and larger amount of culms. A research in China conclusively proved that the canopy of bamboo stand can intercept up to 25 per cent of rain through fall, value much higher than those for conifers and pines. The canopy interception is dependent upon quantity of standing culms and leaf area index in a bamboo forest. The sympodial bamboo also has a high interception capacity.

10.5 Land Rehabilitation

Bamboo acts as healer of lands wounded through human enterprises. The ability to grow in a wide variety of soils, from marginal to semi-arid, makes bamboo perfect for rehabilitation. Bamboo is also a prolific biomass producer, ideal for regenerating soil. In China, India and Thailand, appropriate bamboo agro-forestry modes for cultivation on degraded lands have been developed. In these models, since the subterranean root systems of different components in the community have different distribution, both horizontal and vertical, the bamboo agro-forestry system can fully use the soil fertility, which increases the growth of the populations. The plant is thus, well-suited for use as an instrument for land repair and maintenance. With its evergreen canopy, large biomass accumulation and abundant litter fall, bamboo has been playing a great role in rehabilitation of degraded land. The litter fall from bamboo enriches soils greatly in terms of organic matter, nitrogen, phosphorus, potassium, etc. In Jabalpur farmers are willing to plant *Dendrocalamus strictus, B. bambos* and *B. nutans* on farm bunds and degraded lands even if they are non-productive (Anon, 1997).

10.6 Landslides Prevention

Landslide is one of the most severe types of land degradation, which causes serious topsoil loss and greatly threatens the land productivity. Puerto Rican researchers experimented with several plant species and found *B. vulgaris* to be one of the most effective woody plant in controlling landslides (White and Childers, 1945; Anon., 1997). It develops large thick clumps, makes a rapid dense growth, and planting material has been readily available. For erosion control purpose, bamboo is generally planted in the specific places vulnerable to erosion

10.7 Water Conservation

Bamboo creates a lot of biomass, up to 10 tonnes per ha or more each year, mostly in the form of foliage. Tripathi and Singh (1994) reported aboveground litter values ranging from 4.1 to 7.2 tonnes per ha per year for mature bamboo savannas. Seth *et al.* (1963) reported the aboveground leaf litter production of 3.2 tonnes per ha in a bamboo plantation in India. The leafy mulch which accumulates beneath bamboo collects and conserves moisture in addition to preventing soil erosion.

10.8 Biomass Production

Bamboo growth has been studied with great care in India and the eastern Asia. The highest yield has been attained in a field test in India, focusing on *D. strictus*, leading to a production of 27 tonnes per ha after 18 months at a density of 10,000 plants per ha. This test also demonstrated that bamboo produces most biomass when growing at a high density (albeit with smaller plants), whereas lower densities produced sturdier culms, but lower biomass yields (El Bassam, 1998).

The data in Table 10.2 show estimates of aboveground biomass of some of the Indian woody bamboo species. Data on carbon stock and sequestration rate are not reported for many of the bamboo species (Shanmughavel and Francis, 1996; Singh and Singh, 1999; Kumar *et al.*, 2005; Singh and Kochhar, 2005). Therefore, 50 per cent of the biomass has been assumed as carbon stock (IPCC, 2007). Sohel *et al.* (2015) investigated the carbon storage potential of a common bamboo species, *B. vulgaris* in tropical forest ecosystems of Bangladesh. They reported that five-year-old *B. vulgaris* stand stored a total of 77.67 tonnes carbon per ha, of which 50.44 tonnes was stored in the above ground biomass (culms, branches and leaves), 2.52 tonnes in the below ground biomass and 24.71 tonnes in the soils. Indian studies have reported biomass production of 60 tonnes per ha in *D. strictus* to 319 tonnes per ha in *B. pallida* (Table 10.2).

Table 10.2: biomass carbon stock and sequestration rate in woody bamboo (plantation) in India

Category	Biomass / carbon storage (t/ha Co_2 equivalent)*	Biomass carbon sequestration rate (t/ha/yr)**	Culm density (per ha)	Soil carbon storage (t/ha)	Reference
Bambusa pallida	319/160	13/47.67	35,000	–	Singh and Kochhar (2005)
Bambusa bamboos	287/144	24/88	4,250	–	Shanmughavel and Francis (1996)
Dendrocalamus strictus	60/30	13/47.67	27,000	–	Singh and Singh (1999)
Bambusa bambos	242/121	6/22)	8, 000	-	Kumar *et al.* (2005)
Bambusa cacharensis, B. vulgaris and *B. balcooa*	121/61	–	8,950	57.3	Nath *et al.* (2009)

*Figure in parenthesis is biomass carbon storage in tonnes/ha.**Figures in parenthesis are CO_2 equivalent. (Source: Nath *et al.*, 2015)

10.9 Biomass Estimation Models

The biomass estimation models have been developed for majority of tree species. However, there are no generalized biomass estimation models which can be used for different bamboo species (Brown and Lugo, 1984 & 1992). Development of non-destructive generalized equation for bamboo biomass estimation has been constrained by differences in culm growth behaviour (monopodial, amphipodial and sympodial), species-specific culm and clump characteristics, different culm ages in each clump etc. Species-specific biomass equations for some of the Indian bamboos have been developed following the harvest method (Tripathi and Singh, 1996; Singh and Singh, 1999; Shanmughavel *et al.*, 2001; Kumar *et al.*, 2005; Nath et al., 2009), and examples of equations for aboveground biomass estimation for some major species are shown in Table 10.2.

Table 10.3: Biomass equation for estimation of aboveground biomass of some important bamboo species in India

Species	Location	Culm age	Biomass equation	Reference
Dendrocalamus strictus	Indian dry tropics	Current year >1-yr Dead shoot	Y (g)=3.4053+0.8540 (dbh) Y (g)=5.1162+0.6599 (dbh) Y (g)=5.1797+0.4696 (dbh)	Tripathi and Singh (1996)
Bambusa bambos	Southern India	Across all[a]	Yn(kg)=12.23+37.281 (dbh)	Kumar *et al.* (2005)
B. cacharensis	N-E India	Current year 1-yr 2-yr 3-yr	lnY (g)=2.078+2.140 (ln dbh) lnY (g)=2.134+2.268 (ln dbh) lnY (g)=2.174+2.306 (ln dbh) lnY (g)=2.184+2.178 (ln dbh)	Nath *et al.* (2009)
B. vulgaris	N-E India	Current year 1-yr 2-yr 3-yr	lnY (g)= 2.281+2.149 (ln dbh) lnY (g)= 2.386+2.079 (ln dbh) lnY (g)=2.554+1.956 (ln dbh) lnY (g)= 2.548+1.970 (ln dbh)	-do-
B. balcooa	N-E India	Current year 1-yr 2-yr 3-yr	lnY (g)=2.149+2.284 (ln dbh) lnY (g)=2.199+2.353 (ln dbh) lnY (g)=2.368+2.214 (ln dbh) lnY (g)=2.153+2.477 (ln dbh)	-do-

In regression models, Y is the aboveground biomass, a and b are the regression coefficients and dbh is the diameter at breast height (cm) of culm. [a]Across all refers to biomass equation for all culm ages (Current year, 1-yr, 2-yr, and 3-yr) for that particular species.
(Source: Nath *et al.*, 2015)

10.9 Carbon Sequestration and Climate Change Mitigation

Carbon sequestration is higher in young, fast growing species like bamboo, which absorb more carbon per unit area and time. It varies according to the species, plantation site and management practice (FAO, 1995). According to an estimate, one quarter of the biomass in tropical regions and one-fifth in subtropical regions comes from bamboo (Anon., 1997). If one considers the fact that the great majority of bamboos occur in the tropics within the broad band circumscribed by the Tropics of Cancer and Capricorn, and that about 80 per cent of the area containing bamboo is in the South and Southeast Asian tropical regions, the likely contribution to the globe accounting of carbon sequestration by bamboo alone could be quite significant (Zhou *et al*., 1999).

Bamboos thus, offer one of the quickest ways to remove vast amounts of carbon dioxide from the atmosphere. Bamboos minimize CO_2 gases and generate up to 25 per cent more oxygen than an equivalent stand of trees. One ha of bamboo can sequester up to 62 tonnes of CO_2 per year whereas a young forest sequesters 15 tonnes of CO_2 per year. The Guadua plantations in Costa Rica are reported to absorb 17 tonnes of CO_2 per ha (Janssen, 2000). Another study by INBAR states that over the past 15 years, areas under bamboos in Asia grew by 10 per cent. China, for example, plans to continue to plant more bamboos over the next many years. Studies have estimated that the carbon stored in Chinese bamboo forest carbon stock will increase from 727.08 million tonnes in 2010 to 1,017.54 million tonnes in 2050, which is 40 per cent increase in 40 years. This represents a significant contribution to the Chinese forest carbon stock and a range that shows that policies aiming at combating climate change with bamboos can indeed have significant promise (Kuehl and Yiping, 2012).

Bamboo-based carbon accounting methodologies:

INBAR, Zhejiang A & F University (ZAFU), the China Green Carbon Foundation (CGCF), and the Research Institute of Subtropical Forestry of the Chinese Academy of Forestry (RISF-CAF), developed a "Carbon Accounting Methodology for Afforestation with Bamboo in China". The methodology provides the underlying principles and guidelines on the applied range, design, eligibility, silvicultural practices, selection of carbon pools, GHG emission sources, leakage, baseline scenarios, project scenarios and project monitoring planning for bamboo afforestation projects (Zhou *et al*., 2013)

The Chinese carbon market has responded positively to this novel opportunity to offset emissions with bamboo. As of 2012, more than 10 Chinese companies have already pre-ordered 8155 tonne CO_2 on the Chinese voluntary carbon market through China Green Carbon Fund (CGCF).

Unlike trees, the culm growth in terms of volume growth in bamboos gets completed in one year though culms take few years to mature and during this period some increase in biomass takes place by way of chemical and structural changes. In one reported example (Li *et al*., 2007), air-dried specific gravity of maturing culms increased by about 60 per cent over five years. Compared to unmanaged stands, the cultivation and harvesting practices in managed stands enable much higher per unit area biomass production-with twice higher productivity. INBAR's modeling shows that a managed moso bamboo forest accumulates about 300 tonnes of carbon per ha after 60 years.

Bamboos also produce the most biomass when managed by cultivation with selective, regular harvesting of mature culms. With harvested culms made into durable products, a managed bamboo forest sequesters more carbon than fast growing tree species, such as Chinese fir (Kuehl and Yiping, 2012). Due to rapid early growth, bamboos sequester more carbon in the early years of a plantation than comparable forest trees. On the contrary, the unmanaged bamboo stands do not store high levels of carbon as their productivity is low and the accumulated carbon returns quickly to the atmosphere through decomposition of culms (Kuehl and Yiping, 2012).

10.10 Conclusion

Despite its high potential in carbon sequestration and storage and its important role in livelihood of millions of rural poor worldwide, prospects of bamboo ecosystems, climate change mitigation potential including REDD+ (Reducing Emission from Deforestation and Forest Degradation) schemes still remains to be explored. Thus, there is an urgent need to recognize ecosystem services that woody bamboo provides for well-being of rural communities and nature conservancy. Present knowledge suggests that bamboo offers tremendous opportunity for enhancing the ecosystem goods and services including land and water conservation, climate change mitigation and carbon trading.

The carbon market is now larger than CDM and less stringent rules and regulations have emerged in voluntary carbon markets. In order to give incentive for growing trees/bamboos, a domestic carbon market needs be developed. Forestry based mitigation projects for carbon credits could involve joint forest management, panchayat and community lands. Government can develop guidelines, modalities and procedures for such models. Bamboo is an ideal candidate to be included under various activities of Green India Mission (GIM). Further possibilities of developing bamboo-based carbon mitigation projects could be developed with the active participation of communities. Bamboo could fill an important niche in climate change mitigation, adaptation, and sustainable development with co-benefits of ecosystem services.

The land sector is well-placed to contribute to climate change mitigation. It is a significant source of emissions and numerous opportunities exist for offsetting emissions through sequestering carbon. Experience from Kyoto Protocol reflects that land sector participation under UNFCCC gained limited success due to inadequate finance and/or poor design. The provisions of the Paris Agreement, which are likely to be relevant to the land sector needs to effectively negotiated and lesson learnt from Kyoto Protocol needs to be effectively addressed. The finer details underlying these provisions are developed in a balanced and transparent manner so that land sector is given a fair treatment to deliver carbon mitigation benefits.

CHAPTER - 11

TOOLS AND MACHINERY

11.1 Introduction

Bamboos have varied uses in handicraft, furniture, tool-handles, musical instruments etc. apart from a multitude of many other traditional uses. But the success of any product made out of a natural resource would hugely depend on the tools that are used to make the product since these are the main players in providing value addition to the product. The situation in our country in this aspect is rather alarming. Baksy (2013) reports that out of all artisans surveyed by the Bamboo and Cane Development Institute (BCDI) and the National Centre for Design and Product Development (NCDPD) in the north-eastern region of the country, nearly 93.5 per cent had never been exposed to primary bamboo processing machines, and 92 per cent were using only traditional hand tools.

An account of the local tools has been compiled by Gnanaharan and Mosteiro (1997) detailing the traditional methods followed in primary processing to finishing. According to Reubens (2010), there exists a very limited number of traditional bamboo working tools. It is reported that most of the traditional bamboo craft persons depend on a sickle shaped tool for many of the process like cutting, splitting and slivering. To increase the efficiency, volume and quality of products reduce labour and time, and generate additional income per man-day, modern machinery are needed, that increase in quality and quantity of production. It is necessary to devote attention to tools and machinery in addition to training and skill development through short term, medium term (3 to 6 months) and long term courses (1 year or more). The processing chain of bamboo in making value added products is fairly understood from the early times of usage of this natural resource. Bamboo processing can be divided into three basic parts *viz:* harvesting, primary processing and industrial processing.

11.2 Harvesting

Harvesting is an important aspect to begin with the processing chain of bamboo.The monopodial bamboo can be harvested very easily with the help of portable chain saws as enough space will be there between culms for cross cutting, hence this is most popular way of harvesting in most of the South-East Asian countries and China. But in India majority of the bamboo is of sympodial/clump forming which results in very narrow gaps between culms. Hence, utility of portable chain saws is very limited. The un-cleared clumps become denser and results in degradation of the unharvested culms. Moreover, a dense clump leaves little space for new shoots to grow, resulting in smaller diameter and crooked culms which are not suitable for making value-added products. Thus manual harvesting of bamboo culms with traditional *dao* is more common. Gnanaharan and Mosteiro (1997) reported that felling was usually achieved using simple sharp edged blades and machetes. Harvesting is the most challenging task in unmanaged clumps which is critical in case of Indian bamboos which grows in clump.

The basic harvesting methods for bamboo plantation have been explained by Farrelly (1984). However, a satisfactory and systematic harvesting technique of wild bamboo is yet to be established. One rarely gives consideration for its final intended usage at the harvesting stage of bamboos. The high initial moisture content of bamboo is usually misleading to the harvester because rough methods may easily cause splitting of the harvested material. Information on age of bamboo is very important for deciding harvesting time and final use. The lack of information of age of the bamboo makes it difficult to choose suitable harvesting method and problems arise in processing and utilization later can be avoided.

Thus, some of the factors that should be taken into consideration for the improvement of the harvesting technique to be adopted are age of the culms and the actual end uses. There are various reports on harvesting methods (Farrelly, 1984; McClure, 1967; Wang and Shen, 1987). It is encouraging to see that people are now trying power chain saws in some places which is, however, more useful for monopodial bamboo.

11.3 Primary Processing

A unit for this purpose can be either at or near the plantation site which would save on transportation costs. The tasks at this stage would include grading, making straight cuts on bamboo culms, splitting the culms, making slivers, slices, removing knots etc., from the culms. Simple knives are often used for removal of branches from the main culm (de-limbing) as well as cross-cutting. This leads to non-uniformity in the length achieved for various purposes resulting in low levels of value addition. Splitting, slicing etc., also are done through various types of knives (Gnanaharan and Mosteiro, 1997). On the other hand, a simple bamboo cross-cutting machine can be used for making straight, smooth and square cuts on bamboo culms. Simple cross-cutting machines with suitable power ratings are now available at reasonable costs in India. In the present times, machine manufacturers have come up with two types of bamboo splitting machines:

1. The bamboo splitting machine with knives carries out instantaneous splitting action through knives along the length of the culm. An example is the bamboo chain hydraulic splitter machine available in the domestic market.
2. The bamboo splitting machine with circular saws is employed for producing splits with uniform widths using circular saws. Besides manual radial splitting knife tools are available if there is constraint for power driven machines.

There are machines available for bamboo width sizing, knot removing and planning machine. The knot removing machines can remove knots both from round and split bamboos.

Making slivers is one of the fundamental processes in bamboo based handicrafts. Slivering by hand is a very slow process resulting in low productivity. A slivering machine can enhance productivity for which both imported and indigenous slivering machines are available (Nath, 2016). A bamboo sliver machine produces slivers of thicknesses ranging from 0.6 to 0.8 mm. Bamboo slivers are the heart and soul of mat weaving. Bamboo mats have uses from ordinary range (as a simple mat) to high valued products like composite boards, laminates, etc.

One of the most important primary products of bamboo is the strip. A bamboo slab making machine produces bamboo slabs (strips) which have thicknesses in multiples of that of slivers. While sliver making can be done both manually and with the aid of the machine, a machine is necessary to make bamboo strips of required size and shape (Nath, 2016). Utilization of bamboo in strip form is very advantageous from the point of view of reduction in wastage compared to wood (Gupta *et al.*, 2008). A study demonstrated that bamboos in strip forms resulted in just 5 per cent wastage compared to strips made out of solid wood (~60 per cent).

Few firms in India manufacture different kinds of bamboo processing machines, which can contribute to slicing, splitting, incense stick making, knot removing, etc. (http://www.garnetmachines.com). A number of machinery manufacturers on bamboo primary processing have come up around Dewas, M.P. as demand for these machines is steadily increasing in the country. Fig. 11.1 shows bamboo processing machines in Common Facility Center, FRI, Dehradun.

11.4 Secondary Processing

Lagging or use of inappropriate machinery and equipment has been reported as a constraint in bamboo value chains in South Asia by Kosemund (2016). Reubens (2010) gives an insight into the bamboo-based entrepreneurship in the country. It is argued that bamboo-based enterprises require low capital, raw material and tools and machinery investments compares to other micro, small and medium enterprises. Often bypassing the use of proper tools and machinery leads to unnecessary wastage and compromises on value addition. There is an urgent need for skill upgradation to increase production and reduce wastage. Where electricity costs are a matter of concern, pedal operated machinery can be thought of.

The practice of using old and traditional methods is the main bottleneck in efficient utilisation of the bamboo for quality products (Pandey and Shyamsundar, 2008). Compared to tools used for wood working such as axe, wedge and hammer for opening the timber logs have now been replaced by frame saws, band saws, and associated chipper canters using computerised control, the bamboo sector is yet to come up with standardised tools and techniques. Even the subsequent wood working operations like planing, boring, etc., can be done with portable power tools instead of old hand tools. A similar approach is required to be adopted in the bamboo sector. The circular saws are quite efficient to cross cut the bamboo in green (during harvesting) as well as dry condition (during secondary processing in product making).

The mechanised tools are especially essential for the bamboo based handicrafts sector to improve the quality of surface from the point of view of value addition. A better smoothened surface is essential for an aesthetic appearance. In this direction, a new tool kit was designed and developed by Industrial Design Centre of IIT, Bombay, Mumbai (Rao, 2008). Once primary processed strips/slivers/chips have been prepared they can be used for further industrial processing like incense stick making, handicrafts, mat making and board making.

There are some areas like agarbatti stick making activity wherein non-mechanised process or small machine tools can be used (Pandey, 2008). The bamboo culms can be cross-cut into cylinders using a simple cross-cut saw. For small scale entrepreneurs, these can be then cut into slats and converted to sticks using hand tools. However, mechanization of the process of conversion of the raw bamboo into slats would upscale the manufactured output manifold. In this context, it is heartening to know that about ten women self-help groups in Siphahikhola block of Jorhat district in Assam are already engaged in production of agarbatti sticks through semi-mechanised machines (Bhuyan and Kalita, 2016). Many manufacturers have come out with bamboo round stick making machines.

Bhuyan and Kalita (2016) reported that in recent years, different machines are being used in the bamboo sector in different parts of the world, particularly in China, India and other South Asian countries. They suggested introduction of machinery for faster production and good finishing to promote traditional cottage and medium scale bamboo production units.

Strip-based composite products of bamboo resemble solid wood to a great extent and can be machined like solid wood to convert into furniture and flooring material for house and transport vehicle (Nath, 2016).

Some of the necessary basic machinery needed for a bamboo handicraft unit or summarised below:

- Bamboo cross cut machine: used for conversion of longer bamboo into smaller pieces
- Bamboo knot cum skin removing machine: used in removal of knots and outer skin.
- Bamboo thick slicer machine: used for making thick slices of bamboo for various end uses.
- Bamboo thin slicer machine: Thin slices of bamboo are made using this machine
- Width slicer machine: the slicers can be converted into uniform width using this machine. Uniform width is required for making products like bamboo mat, bamboo basket, etc.
- Bamboo chain splitter machine: used for conversion of round bamboo into splits required for making various end Products.
- Universal bamboo application machine: used for cutting, planing and grooving operations on bamboo.
- Powered hand operated equipment: portable powered tools can be used for cutting, sanding and boring operations on bamboo and wood.

11.5 Industrial Processing for High-End Bamboo Products

11.5.1 Bamboo mat board (BMB)

A cost-effective technology has been developed by Indian Plywood Industries Research and Training Institute (IPIRTI) for the manufacture of BMB sheets as alternative to plywood sheet (Mohanty, 2016). BMB developed are waterproof, resistant to insect and fire, dimensionally stable and possess excellent physical mechanical strength properties. At present four units are manufacturing BMB. Bureau of Indian Standards has brought out a Standard on BMB (IS: 13598-1994 – Specification for Bamboo Mat Board for General Purposes). The hydraulic hot press used for BMB is shown in Fig. 11.2

Bamboo mat based compreg has been found to be an alternative to wood based compreg (Mohanty, 2016). The strength properties meet the requirement of IS standard (IS: 4990 - 1993 specification for shuttering grade plywood in all constructions.

*11.5.1.1 Typical machinery for BMB and Bamboo Mat Compreg Manufacture is given below (*Bansal *et al., 2013)*

- Resin kettle including chemical storage facilities
- Resin applicator
- Drying chamber/band dryer
- Hydraulic hot press (10 daylight with platen size 2.5 m x 1.3m)
- Hydraulic hot press for compreg (high tonnage – 3000 tonne or above capacity with cooling facility)
- Boiler
- Standby generator
- D.D. saw
- Compressor
- Laboratory facilities and measuring/testing equipment
- Blower for cooling coil
- Measuring instrument
- Trolley for material movement
- Water supply including storage facility

11.5.2 Moulded Industrial products

11.5.2.1 bamboo mat corrugated sheet (BMCS) and bamboo mat ridge cap (BMRC)

Bamboo Mat Corrugated Sheet (BMCS) is a roofing sheet made out of bamboo mat and is an alternative to ACCS, GICS, ACS and FRP roofing sheet (Mohanty, 2016). Being made out of bamboo, BMCS is not only eco-friendly, but also possesses high strength and being weather resistant is suitable for roofing. BMCS are light weight, strong and easy to work and hence they require a light supporting structure and are suitable for construction of shelters in earthquake and other disaster prone regions. The Bureau of Indian Standards has come out with a standard for BMCS (IS: 15476 - Standard for Bamboo Mat Corrugated Sheet). The Hydraulic Hot Press used for BMCS is shown in Fig. 11.5. Bamboo Mat Ridge Cap is an integral part of bamboo mat corrugated sheet. The BMRC developed by IPIRTI is compatible with BMCS. (Fig.11.3)

11.5.2.2 Bamboo mat moulded skin board (BMMSB)

A wooden door, in any shape and form, is most popular among users. One variant of the door uses High Density Fibre (HDF) board as door skin on a wooden frame. HDF is usually made from wood fibre and door skin made of moulded HDF is imported from the US to India. Moulded door skin made out of woven bamboo mat can be a suitable replacement for HDF door skin. Use of moulded bamboo mat door skin has many advantages. It possesses higher physical-mechanical strength than HDF and bamboos mats can be given any shape in moulded platen during hot pressing (Mohanty, 2016).

*11.5.2.3 Typical machinery for BMCS, BMRC and BMMSB manufacture is given below (*Bansal *et al., 2013)*

- Resin applicator
- BMCS hot press (Multi daylight) 2.50m x 1.25m with moulded platens
- BMRC hot press (Multi daylight) 1.35m x 0.5m with moulded platens
- BMMSB hot press (Multi daylight) 2.15m x 1.05m with moulded platens
- Band dryer
- Drying chamber
- Scissor lift
- Boiler
- DD saw
- Standby generator
- Compressor
- Resin plant
- Chemical storage tank
- Glue spreader
- Glue mixer
- Dust extractor
- Cold press (for overlays on BMMSB)
- Water storage tank and pump
- Knapsack for chemical spraying

11.5.3 Bamboo laminates (BL) and bamboo lumber

One of the most exciting application areas for value added applications of bamboo is the manufacture of bamboo laminates and lumber segment. Bamboo laminates/lumber can replace timber in many applications such as doors and windows, frames, partitions, furniture, flooring and some structural applications (Mohanty *et al.*, 2017).The hydraulic hot press used for BL and lumber are shown in Figs. 11.4 & 11.5.

*11.5.3.1 Typical machinery for bamboo laminates and lumber(*bansal *et al. 2013)*

- Resin kettle and chemical storage tank
- Glue mixer
- Glue spreader
- Boiler
- Hot press with horizontal and vertical pressure facilities (for laminates)
- High tonnage hydraulic block press.(for lumber)
- Drying chambers
- Pressure impregnation plant
- Trimming machine
- Thickness slicing machine
- Four side planer
- Sanding machine
- Tongue and groove cutter
- Set of machinery finishing/coating.
- Compressor
- Trolley for material movement

11.6 Equipment for High-End Bamboo Boards

Bamboo boards are very abrasive due to the resin content and the silica in the bamboo. These result in very high rate of tool wear out when machining bamboo boards. Hence, special tools for machining the bamboo boards for different processes like cutting, shaping and drilling are required. For example, saw blades that are used for wood or plywood cannot be used on the bamboo board. Some companies claim to have solutions to address these problems through a range of products (http://www.leitzindia.com/machining-bamboo-board.php).

11.6 Tools and Machinery for Handicraft Industry

Bamboo woven articles are made with various widths, thicknesses, and lengths of bamboo splits made from bamboo culms, based on the design of the products. There are two kinds of bamboo splits used for weaving: bamboo threads and bamboo strips. The thickness and width of threads are approx. equal. Strips are much broader than they are thick. Bamboo is traditionally used in rural areas for weaving products or handicrafts. Manual crosscutting, splitting and slivering of bamboo culms is normally done by men with various tools like knives. It is possible for people to weave products such as mat and baskets after short-term training. Higher level of experience and skill are required to weave superior quality handicrafts and these can only be learnt from master craftsmen and women.

11.7 Hand Tools

Dao, bench vice, hand saw, hack saw, hammer scrapper, chisel, c –clamp, measuring tape, hand planer are the common hand tools, while power tools are pillar drill machine, hand drill machine, angle grinder, orbital sander, hand jig portable cross cut, hand plane etc. The traditional method of bamboo processing practiced by craftsmen in villages is purely a manual processing operation using only one tool called 'dao' or knife. All processing activities like cross cutting, splitting, slab, sliver, stick making etc. are done with the help of this tool. The MBDs produce traditional products using traditional tools often handmade (Fig. 11.1) which when compared to modern tools can be more labour and time consuming. The manual processing of bamboo is very labour intensive, tedious, and monotonous. It also leads to the production of poor quality slivers, sticks, etc., and generates more wastage of raw materials. The traditional tools used are shown in Fig.11.6.

Fig. 11.1 : Bamboo processing machines in common facility centre, FRI, Dehradun.

Fig. 11.2 : Hydraulic hot press for manufacture of BMB

Fig 11.3: Hydraulic hot press for manufacture of BMCS

Fig 11.4: Hydraulic hot press with lateral pressing for laminates

Fig 11.5: High tonnage hydraulic block press.(for lumber)

Fig. 11.6: Traditional tools for bamboo working

11.7.1 Bamboo cross cutting machine

This machine is used for making a straight, smooth and square cut across the culms without development of any additional splits on the culms and leads to drastic reduction in a raw material wastage. A tungsten carbide tipped (TCT) circular saw is used for cross- cutting bamboo culms and it needs periodic re-sharpening. There is a provision in the machine where the desired length of bamboo to be cross-cut can be preset. Safety guards are provided on the machine to take care of the safety aspects during operation.

11.7.2 Bamboo splitting machine with knives

The main function of this machine is to carry out splitting of bamboo culms with knives to the desired width. The tool used for splitting is called knife ring. Knife rings are available with knives placed at different interspaces and the one that suits the diameter of bamboo culms and the intended width of split can be selected. The bamboo culms are pressed and moved fast against the knife ring with a pushing device moving on a sliding bed, which resuls in instantaneous and simultaneous splitting action. Safety guards are provided on the machine and should be in place to take care of safety in operation. However, adequate precautions are taken during operation of the machine to prevent accidents and injury.

11.7.3 Bamboo splitting machine with circular saws

This machine is employed for splitting bamboo using circular saws to get parallel width. The advantage of this machine is that uniform width can be obtained for split even if there is tapering in diameter of bamboo culms. Uniformity in split is a very essential requirement in the manufacture of bamboo laminates or floor tiles. In this machine, two parallel mounted TCT circular saws set to the desired split width, do the cutting action.

11.7.4 Bamboo width sizing, knot removing and planning machine

This machine is very effective in carrying out the planing operations as the work is done by two carbide cutters. There is also provision in the machine to do other functions such as width sizing and knot removal, with the help of sizing knife and knot removing knife, respectively.

11.7.5 Bamboo four side planning machine

Planing of all four sides of bamboo strips is done by this machine with the help of four carbide cutters for the production of bamboo laminates. The width and thickness of the strips can be set in this machine and smooth surfaces and uniform size for all the strips are thereby obtained.

11.7.6 Bamboo one side planing machine

The planing of bamboo laminate after hot pressing operation is carried out by this machine. At one pass, one surface of the laminate is planed using a planing cutter to a smooth surface.

11.7.7 Bamboo slab making machine

This machine is utilized for the productions of slabs as a preparatory step to the manufacture of silvers for mat making. A horizontally mounted slicing knife, whose position can be altered depending upon the thickness of slab, does the cutting action. The thickness of slab is normally set to 2.4 mm or in multiple of final sliver thickness.

11.7.8 Bamboo sliver making machine

The slivers used for weaving mats are produced in this machine. A horizontally mounted slicing knife, whose position is moved up or down depending upon the desired thickness of sliver, does the cutting action. The normal thickness of sliver is about 0.6 to 0.8mm.

11.7.9 Bamboo outer node remover

It is used for removing the outer node of bamboo prior to splitting.

List of tools and equipment for bamboo processing

Combination pliers 200 mm insulated
Screw driver 100mm, 200 mm
Neon tester 500v pencil bit type
Electrician knife
Hammer ball pen 250 gm
Halfroundfile 12”
Half round chisel 10”
Hammer ball pin 500 gm
Center punch 100 mm
Steel measuring tape 20 m
Allen keys set
Spanner double ended set (6-37mm)
Adjustable spanner 8”x10”x12”x14” (each 2pcs)
Steel rule 300 mm
Electric soldering iron 35 w
Electric soldering iron 125 w
Tong tester
Megger
Common hacksaw
Adjustable hacksaw
Hand saw(450 mm)
Round knife
Radial hand splitter (4.8.12.16 blades)
Dao 8”and 12”, each 20pcs
Pruning scissor
Handrill
Electric handrill
Idc gauge
Bamboo crosscut machine, heavy duty including 2 h.p. Motor, starter and tungsten carbide tipped circular saw 16” x 3 mm x 120 teeth

- maximum diameter of bamboo to be cut: 200 mm (8”)
- dimensions of the machine, (including front & back guider): 17'x4'x2.5'”

- Power consumption: 2 hp
- Spindle speed: 2800 rpm, spindle speed: 2800 rpm

Bamboo portable crosscut machine, including 2 h.p. Motor, starter and tungsten carbide tipped circular saw 14”x3 mm x 120 teeth
- Maximum diameter of bamboo to be cut: 150 mm (6”)
- Power consumption: 2 hp
- Spindle speed: 2800 rpm

Bamboo radial splitter (chain type)including various grill for different diameter of bamboo
- Dimension of the machine: 140”x40”x40”
- Power consumption: 5 hp
- Max., length of bamboo that can be split: max. 8 feet.
- Diameter of bamboo to split:8

Bamboo round stick making machine
- Dimension of the machine: 30”x30”x48”
- Net weight: 450 kg
- Power consumption: 7 hp
- Max. Width of the bamboo strip: 25 mm
- Specification of cutters
- Carbide tipped planer cutters1no.: 100x25.4x25x7 teeth, carbide tipped stick making cutters, 2 nos.: 78x25.4x25x12 teeth (1.5mm & 3mm)

Bamboo square stick making machine
- Dimensions:18”x22”x8”
- Power consumption: 1 HP

Bamboo stick polishing machine: Dimensions of the machine (in metre): 3.8x1x1.3, power consumption: 2 hp, maximum length of sticks: 18”

Bamboo inside node removing-cum-slicing machine (heavy duty): Dimensions of the machine (in metre): 1.2 x 1 x 1.3, power consumption: 2 HP, Maximum width of bamboosplit: 40mm, minimum thickness of strips that can be produced: 1.5mm, maximum thickness of strips can be produced: 10mm

Bamboo stick sizing machine: Maximum height of the bamboo lump: 100mm, dimension of the machines, in metre: 1.2 x 1.2 x1.5 power consumption : 2 hp Carbide tipped circular saw : 400x25.4x120 teeth (2.2 thickness)

Bamboo double side cutting machine, parallel splitter maximum diameter of bamboo to be split : 8”, dimension of the machine, in metre : 2.3 x1.3 x 1.3 maximum diameter of circular: 14” x 2.5mm x 80-100 teeth power consumption: 3 hp x2, spindle speed:2700rpm

Bamboo two side planning cum sizing machine: maximum width of bamboo to be planed 35mm dimension ofthemachine:74”x22”x41” Power consumption: 8 hp

Bamboo four side planing machine: Maximum width of bamboo: 35mm, dimension of the machine,

(in metre): 1.5x1.2x1.6, maximum thickness of bamboo: 20 mm, power consumption: 7 hp.

Bamboo treatment tank: Outside dimensions of the treatment tank: 9'x2'x3', maximum temperature for bamboo seasoning unit: 120°c. Chemical recommended: boric/borax acid, metal sheet (thickness 2 mm): stainless steel

Bamboo drying tank: Outside dimensions of the treatment plant: 2'x2'x1.5' maximum temperature for bamboo seasoning unit: 120 °c. chemical recommended: synthetic or natural chemical, metal sheet (thickness: 2 mm): stainless steel

Bamboo outside knot removing machine: Power 1 HP height of the table: 30".

Bamboo double side cutting machine: Parallel splitter maximum diameter of bamboo to be split: 8”, dimension of the machine, in metre: 2.3x1.3x1.3 maximum diameter of circular: 14” x 2.5mm x 80-100, power consumption: 3 hp x2, spindle speed, in revolution per minute: 2700rpm

Bamboo two side planing-cum-sizing machine: Maximum width of bamboo to be plane : 35 mm, dimension of the machine:”22”x41”powerconsumption: 8 HP

Bamboo four side planing machine: Maximum width of bamboo: 35 mm dimension of the machine (in metre): 1.5x1.2x1.6, maximum thickness of bamboo: 20 mm, power consumption: 7 HP

Bamboo treatment tank: Outside dimensions of the treatment plant: 9'x2'x3', max. temp. for bamboo seasoning unit: 120 chemical recommended: boric/borax acid metal sheet (thickness 2 mm): stainless steel

Bamboo outside knot removing machine: power consumption: 1 hp Height of the table: 30”

Portable sanding machine, spray gun

Bamboo slivering machine

11.8 Conclusion

Though a wide range of tools and machinery are now available in India, they are yet to reach the grass root level, i.e., the rural people and artisans, who use bamboo for their livelihood by making small-scale products. The need of the time is to open cooperative facility centres equipped with all basic machinery and make them accessible and available to the rural poor. This step would improve the productivity and enhance the level of value addition.

“One specific lacuna in the development of tools and machinery specific for bamboo which would need support from institutes like National Institute of Design or other competent institutes. Considering its significance for sequestering carbon, corporate sectors should be roped in for carbon credits”

- Dr. Muyeed Ahmed, Project Coordinator at PoinTec Pens and Energy Pvt. Ltd., Bengaluru

SECTION-III
Developing Enabling Policy Environment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LEGAL AND POLICY ISSUES

12.1 Introduction

Legal and policy interventions required for promotion and development of bamboo-based economy have been suggested from time to time (Mohanan *et al.*, 2002; Baksy, 2013; Aggarwal, 2014; Arshad and Reza, 2015; Sinha and Deb, 2016). Several conferences, symposia, seminars and workshops have dwelt on legal and policy issues and expressed that there is an urgent need for policy interventions to promote bamboo cultivation, supply, processing and value addition, products manufacturing as well as utilization and marketing in a balanced manner, with ultimate goal of evolving the bamboo sector development into a thriving economy with litlle of no impct on environment. The hitherto excessive thrust on bamboo extraction from natural forests, utilization and marketing has potential danger of resource depletion with diminishing bamboo diversity and hence, must be avoided. Bamboo is a resource that is capable of socio-economic transformation, besides improving the quality of forests. Bamboo, therefore, needs to be declared as a priority sector. The suggestions on legal and policy issues, broadly in the category of resource management, processing and marketing are summarized here.

12.2 Bamboo Regulation in India and Need for Reforms

Bamboo definition, cultivation and transportation are currently covered by various legislations and policies of the Government of India and the States, and judgments of the apex court (Jamatia, 2014):

12.2.1 Indian Forest Act, 1927 (IFA) **-** classifies bamboo as a tree, while scientifically it is classified as a grass. Bamboo when felled is considered as timber and IFA regulations/restrictions apply for its transportation irrespective whether felled bamboo is from forest or private land. Various transport and pass/permit-related restrictions do not allow free movement of bamboo as long as it is considered as timber

12.2.2 Forest Conservation Act, 1980 (FCA) - deals with restriction on allotment of forest land for non-forest purposes and de-reservation of reserved forests. It essentially expands the scope of the IFA and enhances Government control over the forest, making it difficult to remove restrictions once they have been put in place.

12.2.3 Forest Rights Act, 2006 (FRA) - classifies bamboo as a non-timber minor forest produce. It vests the right of ownership and the right to collect, use and dispose bamboo in the forest-dwelling communities as a part of their traditional rights. The FRA restricts the development of bamboo industry by attempting to vest the right to trade in bamboo in the tribals.

12.2.4 Panchayats (Extension to Rural Areas) Act, 1996 (PESA) - grants Gram Panchayats (local self-government bodies) the ownership of minor forest produce (MFP) and defines their role in MFP management and conservation in PESA States, though this is yet to be implemented.

12.2.5 Former Minister for Environment, Forest and Climate Change (MoEF&CC) - Mr. Jairam Ramesh in his letter of 21st March, 2011 to the Chief Ministers of all States, had urged the States to treat bamboo as an MFP. The MoEF&CC in a circular dated 14th May 2013 had further urged States to remove transit pass requirements for bamboo grown on private lands.

12.2.6 Supreme Court Judgment - The Supreme Court *inter-alia* classified bamboo as a MFP and exempted it from the ban on felling of trees from forests in 1996. This implies that bamboo was not considered to be a tree by the Court, and felled bamboo was not to be considered as timber. This again contradicts the Indian Forest Act, which classifies bamboo as a tree, and, consequently, defines harvested bamboo as timber.

12.2.7 Forest Acts/Regulations at the State level cover government forests, private forests and private plantations alike - especially applicable when bamboo continues to be defined as a tree in the IFA. Though States are vested with the power to exempt bamboo or any other forest produce from transit regulation under Section 41(3) of the IFA, it is not exercised. Barring the first two and the last, the other legislations/efforts have faced stiff implementation challenges and are yet to deliver the intended benefits. The specific issues that stand in the way of free bamboo transportation and trade as a source of livelihood are summarized below:

- Indian Forest Act, 1927 defines certain forests as restricted, to which only authorities have access, bans felling of trees and defines bamboo as a tree. It also prevents felling of bamboo on both private and government lands and its utilization for personal livelihoods. State policies further ban bamboo felling in private forests and transportation without permits under Forest Conservation Act, 1980.
- Forest Conservation Act restricts the scope for de-reservation of forests and extends control by authorities on previously reserved forest lands.
- Scheduled Tribes and Other Forest Dwellers (Recognition of Forest Rights) Act, 2006 (FRA) recognizes rights over collection and disposal of MFP by tribals vested with rights, provides Gram Sabhas the ownership of Transit Passbooks, maps out claims to land, forests, forest produce, etc. Panchayats (Extension to Rural Areas) Act, 1996 (PESA) Grants Gram Panchayats ownership of MFP's and defines their role in MFP management and conservation. In PESA, States grant local self-government bodies powers over MFP management.
- The opportunity to leverage this valuable resource is further constrained by the number of Ministries who oversee regulations relating to it. Different legislations have authorized different Ministries to make rules. The Indian Forest Act is administered by the MoEF&CC, while Forest Rights Act is administered by the Ministry of Tribal Affairs and the National Bamboo Mission (now National Agroforestry and Bamboo Mission) has been set up under the aegis of the National Horticultural Mission of the Ministry of Agriculture and Farmers Welfare, all under Govt. of India.
- Lack of co-ordination between these Ministries results in arbitrary legislations, as is evident from the multiple contradictions among the legislations along with haphazard policy implementation. The lack of a single regulatory body to oversee the growth of the bamboo sector has led into wasted potential, which is evident when one compares the situation of bamboo with the achievements of the Tea, Coffee or Rubber Boards (Jamatia, 2014).

Outdated and Unimplemented Laws:

- The IFA, promulgated in 1927, is 90 year old and in need of a comprehensive revision to make it address the needs of India today and also to make it consistent with the legislations passed since then. The Standing Committee on Science and Technology of the MoEF&CC has observed the pressing need for amendments in the IFA in its report submitted in November 2012- specifically on the need to amend the colonial spirit of monopolizing forest resources - to harness maximum revenue, which underscores the IFA in its current form and to harmonize it with the FRA.
- Simply amending the IFA is not enough because the implementation challenges faced by FRA will continue to impede the access of forest dwelling communities to bamboo and other forest produce. Non-implementation of the FRA in its true spirit has led to various troubles with regard to the infringement of the rights of tribals, whereby they have been incarcerated for simply exercising the rights guaranteed to them by the Forest Rights Act.
- Finally, the implementation of FRA will not be sufficient if transit pass requirements continue to burden this sector. Forest dwellers enjoying their right to harvest and transport bamboo is a necessary first step. However, if the upstream producers/manufacturers of bamboo or bamboo products continue to face transit pass requirements, it will dampen both the supply and demand scenarion. Hence, this has to be removed, in line with the circular dated May 2013 from the MoEF&CC to the States.

Non-regulatory Issues :

- While regulatory problems have stifled the potential of the bamboo industry and the rural economy, non-regulatory problems have also played a huge role in not allowing even the rural populace to be able to fully exploit this resource to its optimum level. Progress is hampered not only by red-tapism and bureaucratic inefficiency, but also through the lack of information, lack of institutional credit and restrictive rules. The impediments include high transport costs associated with agro-forestry and non-uniform rules with regard to inter-state transport. Further, problems of institutional support include lack of incentives, lack of economic viability, lack of rational taxation, lack of awareness, etc

12.3 Creation of National and Regional Bamboo Policies

12.3.1 National Bamboo Policy

It is recommended that a National Bamboo Policy should be formulated as the first step towards developing the bamboo sector. Such a policy would serve to outline the fundamental principles that would guide State interventions in the bamboo sector, particularly in terms of balancing industry needs with ecological concerns. It is recommended that this policy must include the balance between economic and ecological concerns and the resolution of conflicting classifications of bamboo.

Regulatory confusion has often been cited as one of the most important impediments to the optimal utilization of existing bamboo resources. On one hand, The Indian Forest Act, 1927 classifies bamboo as a “tree” thereby placing it under the sole ownership of the government and vesting felling rights solely in the Forest Department. On the other hand, the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 includes bamboo in Minor Forest Produce thereby vesting forest-dwelling communities with the right to harvest and utilize bamboo without interference. The rationale behind the classification of bamboo, along with similar forest products, as a tree was to protect it from over-exploitation thereby ensuring regeneration and maintenance of biodiversity. On the contrary, the inclusion of bamboo in minor forest produce has been justified on the basis of the customary and livelihood rights of communities.

In essence, this definitional dichotomy reflects the conflict between the above-mentioned ecological and economic concerns. While developing the bamboo industry is undoubtedly essential, concerns regarding conservation and sustainable use cannot be ignored. Therefore, it is recommended that, rather than strictly classifying bamboo as a tree or minor forest produce, the aforementioned regulatory confusion should be resolved by according it the status of "non-timber forest produce” (not to be equated with the "non-wood forest produce or NWFP) in the National Bamboo Policy and amending the Indian Forest Act and the Forest Rights Act to reflect the same. This would enable, individuals, communities and government agencies exploit bamboo for economic purposes under supervision of the District Bamboo Board (in order to ensure that exploitation is done in a sustainable manner). This process has been explained in detail in the section on District Bamboo Boards.

Still the major source of bamboo (to the extent of about 85 per cent) are the natural forests, which are either government- or community-owned (*e.g.*, north-east India) or in which right to collect bamboos is vested on individuals under Forest Rights Act, 2006. There is an obvious need for stakeholder-centric rather than just stakeholders' participation-oriented National Bamboo Policy with a paradigm shift from naturally-sourced bamboo to mass-scale bamboo plantation on farm lands, fallow lands, wastelands, river bank, etc. Bamboo plantations in forest lands, however, need to be regulated or promoted keeping in view the biodiversity conservation and the climate change mitigation issues.

12.3.2 Regional Bamboo Policies

Apart from the National Bamboo Policy for the country as a whole, it is recommended that Regional Forest Policies, emanating from the National Bamboo Policy, should be developed for five sub-regions in order to account for variations in native species, scale of harvesting, and usage patterns. These five sub-regions would be as follows:

a. The North-West Region

b. The Ganga Basin

c. The Central Region

d. The North-Eastern Region

e. The Southern Region

12.3 Administrative Structure for Management and Use of Bamboo Resources

It is recommended that the National and Regional Bamboo Policies be implemented through a three-tier structure with a National Bamboo Board, State Bamboo Boards for every state or a group of states and District Bamboo Boards for every district or group of districts.

12.4.1 National Bamboo Development Board

The National Bamboo Development Board will function under the direct administrative control of the Ministry of Environment and Forests and would have a largely supervisory role. Principal Chief Conservators of Forests (Social Forestry) or equivalent officials of all states will be the members of this body.Its functions would include:

- formulation and implementation of National and Regional Bamboo Policies,
- advising the Government of India on any matter concerning the management, conservation and marketing of bamboo and bamboo products,
- providing technical and regulatory support to State Boards as well as coordinating their activities and resolving disputes among them,
- laying down industry standards for bamboo raw materials and final products and publishing manuals and guidelines for implementation of the same,
- conducting and sponsoring research into all aspects of bamboo production and sale including conservation and propagation strategies, development of new technologies for more efficient preparation and processing and developing new economic models and strategies that are both efficient and inclusive,
- planning and organizing training of persons engaged in harvesting, growing, preparation or processing bamboo,
- conducting a comprehensive re-branding campaign for bamboo and bamboo products and generating mass awareness about the many benefits of bamboo and bamboo products, and
- collecting, compiling and publishing statistical data on harvesting and production, manufacturing and usage patterns and export patterns;

12.4.2 State Bamboo Development Boards

State Bamboo Development Boards would be responsible for making targeted policy interventions that would support and expand the production of bamboo and bamboo-based products as well as the market for the same. The Board will be headed by official of the rank of Chief Conservator of Forests (Social Forestry). These interventions would include:

- implementation of National and Regional Bamboo Policies as well as strict adherence to industry standards laid down by the National Bamboo Boards,
- providing technical and regulatory support to District Boards as well as coordinating their activities and resolving disputes among them,
- setting up primary processing factories in each bamboo cluster for primary value addition before supplying to the industries. This will avoid wastage of the resource, besides generating employment locally;
- capacity building of farmers, artisans and owners of processing units through initiatives such as- providing improved designs and tools; short term trainings; providing financing to entrepreneurs in bamboo-based industries; linking urban consumers and export markets to the local artisans; creating business development help desks (for aiding in creating business plans, providing information to producers, business counselling, market information and technology information) and digitising information on bamboo resources, producers, consumers, technology, market information etc.

- entering into MoUs with engineering and technology institutions for development of improved tools, equipment and machinery for bamboo harvesting and processing,
- promoting semi-mechanization in bamboo-based industries like incense sticks/ handicrafts/ furniture and promotion of industry clusters in the bamboo growing areas which will ensure value addition and employment generation. District or Block level clusters can be formed, and Common Facilitation Centres with required machinery can be provided. Alternatively, bamboo cooperatives can be formed with the bamboo farmers to collectively take up cultivation, processing and marketing,
- providing support to ancillary industries in order to ensure continued growth of bamboo-based industries. Fir instance, incense stick production is one major use of bamboo at present. However, local value addition is lacking in the place of production of sticks due to lack of other ingredients and expertise. Large scale planting of *Litsea glutinosa,* the source of adhesive for making incense sticks, on private lands and training of the owners in sustainable harvest of bark, will promote in-situ utilization of bamboo sticks for production of incense sticks in north-east India, thus increasing value addition and employment generation,
- undertaking vigorous promotion of bamboo products both in domestic and international markets, and extension and monitoring for coordinating bamboo sector programmes with other development programmes.
- ensuring that people of traditional bamboo-dependent communities, forest-dwellers and other weaker sections of society are employed in bamboo industry on a priority basis, other things being equal, to ensure social justice.

12.4.3 District Bamboo Development Boards

The members of the District Bamboo Development Board will include representatives from the Forest Department, Panchayats and Gram Sabhas, agriculturists, the processing industry and the manufacturing industry. The body will be headed by Divisional Forest Officer of the concerned Division. This will ensure that the needs and concerns of all stake-holders are taken into account and a balance between economic and ecological concerns is achieved. The role of District Boards will be particularly important in improving supply of with reference to both harvesting from natural forests and production by private parties. Their duties will fall under the following categories:

(i) Regulation of harvesting from forests

The natural forests from which bamboo is currently sourced suffer from heavy biotic interference, low productivity and poor management. The District Board will ensure that the productivity of bamboo clumps is increased through appropriate silvicultural interventions such as removing congestion, mounding to promote shoot formation, and water conservation measures in arid areas. At the same time, strict regulation of harvesting is essential to avoid over-exploitation and consequent depletion of resources. To that end the Board will closely monitor the quantom of bamboo being harvested in all forests under its jurisdictions.

Board will be further empowered to prescribe the minimum number of culms to be retained after harvest. Further, aided natural regeneration, especially in those areas where there is sporadic flowering and seeding and enrichment planting with nursery grown seedlings can also be done to increase the growing stock. Grazing in these areas, at least during the regeneration time of bamboos, needs to be strictly controlled. In government owned forests the forest departments should carry out this activity, while in community owned forests, the forest departments can do this collaboratively with the people and the District Board will provide all necessary support for the same

(ii) Promotion of private bamboo plantation

As has been recommended above, private plantation of bamboo should be encouraged in order to maintain necessary supply for expansion of bamboo-based industries. This can be done by providing planters with subsidised seeds, capacity building programmes (including those on sustainable harvest of culms/ shoots), financial support at subsidised rates, etc. Board can also undertake registration of private producers so as to better monitor growth of bamboo supply as well as maintenance of quality standards.

12.5 Additional Role of State Forest Department and Research Institutions

- The Forest Departments in the States are important stakeholder in the bamboo industry, particularly in the context of harvesting and as such will be represented in the Bamboo Boards and will also provide support to the Boards in discharging their functions. In particular, the Department can provide technical and scientific support. For instance, for the development of bamboo industries, there is a need to focus on a limited number of commecially valuable species, which will ensure uniformity of product, and standardization of processes. Fast growing woody species that do not flower or have long flowering cycles are preferable and in the selected species, high-yielding genotypes need to be selected by genetic combing and mass multiplied by ICFRE and its centres for supply to the planting agencies. Multi-location trials across varying environments are required to select genotypically stable clones and also for clone-site matching. Successful cases of selection and mass multiplication which has increased yield are Phyllostachys heterocycla var. pubescens in China and one clone of Bambusa balcooa in south India.
- Massive planting efforts would require large scale production of quality planting stock. Large bamboo nurseries should be established in the bamboo growing areas, by the forestry research organizations and social forestry wings, to supply sufficient planting stock. Production of planting stock through seeds, vegetative propagation and tissue culture should all be adopted depending on the species and the protocol that is suitable. In addition community nurseries can also be raised to provide employment and to decentralize the activity, but with required training.
- Protocols for raising the plantations and their management which are already standardized should be popularized, and the farmers should be trained in management of the plantations by the research organizations. Capacity building of farmers in bamboo propagation and plantation management must be ensured through reputed research organizations or universities.
- To ensure constant supply of seeds in case of the species that are flowering sporadically, seed orchards can be raised in blocks, each block from seeds collected in a particular year. If seeds are collected every year and blocks are added, at the end of the flowering cycle, there will be seed production serially in these blocks, which can be replanted with the seeds of that year. This will ease the production of planting stock.
- Since basic information on the species wise growing stock is lacking, resource mapping employing remote sensing tools is a priority.

12.6 Other Policy Interventions

12.6.1 Allocation of land for bamboo plantations

Apart from the regulatory framework outlined above, it is recommended that the following policy interventions be made in order to strengthen the bamboo industry:

- It is estimated that at least 5 lakh hectares need to be brought under bamboo cultivation. This has to be done by special missions undertaken by the forest departments, forest corporations, horticulture departments and bamboo based industries.
- Promotion of plantations on a large scale in the private lands, community lands and wastelands, with provision of subsidy for raising such plantations, can improve the growing stock outside forests. The non-forest government lands that do not support any tree cover, may be leased to panchayats, bamboo based industries, or forest corporations for raising bamboo plantations. The land adjoining the national highways and railways can be used for raising large-scale bamboo plantations, for supply of raw material to industries.
- The land adjoining major rivers, such as, Ganga, Yamuna, Brahmaputra, etc., can be planted with bamboos as a riverside belt plantation, to reduce the silt load getting into the rivers and also to reduce the floods and bank erosion. Continuous harvest of bamboos from these lands will help in meeting the domestic needs of the nearby villages and also the industries. The local bodies, viz., the panchayats, municipalities and corporations can be entrusted the responsibility of maintaining these plantations, and the yield can be a source of revenue for them.
- Massive planting in private lands, not fit for agriculture or in agroforestry systems in combination with horticultural crop or medicinal plants is essential to meet the anticipated demand.

- The bamboo based industries should be encouraged to adopt contract farming either taking the farmland on long term lease and cultivating the land with bamboos or alternatively providing necessary inputs for bamboo plantation at subsidized rates and buying the produce through a buy-back arrangement. To ensure the quality of the planting stock and appropriate silviculture tri-partite arrangements can be made among the industry, farmer and a research organization of the State or Centre. If financing is also required, quadripartite arrangement can be done, adding a bank to the group. This would ensure timely payment to the farmer and assured supply of raw material for the industry. Such arrangements are working well in case of pulpwood plantations in South India, and can be easily replicated elsewhere.

12.6.2 Amendment of transit rules

A lot of suggestions have been made in the past to remove the restrictions on the felling and movement of bamboo. Restriction on felling of bamboos grown on private lands can be completely removed. Normally it is necessary to control the transit of all forest produce, including bamboos, for various reasons, viz., to deal with thefts effectively, to prevent excess removals by those permitted to remove, to facilitate collection of duties and fees leviable on the produce and to enable identification of produce belonging to government or public when in transit. However, law empowers the government to exempt any class of timber or forest produce from the said control, on the basis that these rules should not be a source of unnecessary harassment to the public and that control of transit of forest produce is required only in those areas where the vulnerability to theft is high and not in places where there is no such risk (John Joseph, 2002).

Applying this logic, restriction on any bamboo which is not native to a particular State, or that is exotic, or largely found only under private ownership is unwarranted. However, restriction on the bamboos native to the State would be required, as most of the bamboo as on date is found only in the forest areas, and bamboos outside forests are not enough in volume to justify total relaxation of control over transit. In community owned forests, the community based organizations may devise means to impose the restrictions on movement, mainly to restrict excessive removal and to keep account of the harvest. The controls can be relaxed or removed once a large proportion of bamboos get cultivated and harvested only from private holdings.

12.6.3 Support through creation of government demand

- Procurement of bamboo products by the Government in offices, educational institutions, rest houses, etc. should be encouraged through Government orders, at least to the extent of 25 to 50%. The use of bamboo-wood which is a novel product and a substitute for wood needs to be encouraged by stipulating use in the Public Works Department of both the Centre and the States. This would serve as demonstration for other building agencies to emulate, and thus would create demand for the product.
- The use of bamboo in pulp and paper industry should be encouraged. This would reduce the need for import of pulp and create domestic demand.
- Bio-energy (bio-ethanol, charcoal, etc) production from bamboo is a new attempt and needs to be supported, by stipulating compulsory blending with fossil fuels.
- Armed forces and paramilitary can greatly benefit from innovative bamboo products. The 'pack-flat' and 'knock-down' pre-fabricated houses can be easily transported and dismantled. Such housing units can save a lot of cost on material and transport.
- Bamboo bridges in remote areas would also solve a lot of problems of commutation for the rural populace as well as for the armed forces, who often have to construct such bridges at a very short notice.
- Organizations such as DRDO, IPIRTI and ICFRE must collaborate to develop such products. A policy directive in this regard by the government is most essential.
- Sale of bamboo products must be promoted through regularly held trade fairs, bamboo expos, bamboo haats, bamboo emporiums, etc.
- Use of bamboo-made pre-fabricated houses must be promoted in earthquake-prone areas. Such houses, often called 'pack-flat' and 'knock-down', can be easily packed in boxes, transported and assembled.
- Awareness programmes of architects, builders, civil engineers should be organised for generation of awareness about bamboo in construction. In fact, Bamboo as structural and constructional material should be included in the curriculum of architecture and design courses at university level.

12.6.4 Interventions to ensure competitive pricing

Wherever the farmers are cultivating bamboos on their own, minimum support price should be fixed by the Government from time to time for sale to industries, in order to encourage bamboo cultivation and to avoid loss to the farmer.

Considering the environmental benefits of cultivating bamboo and the large-scale employment potential, raw bamboo, primary processed bamboo products (such as bamboo woven mats) and handicrafts of bamboo should be totally exempted from GST. The concessions that have been given to the solar energy industry, should also be extended to the bamboo based ethanol or other power producing units.

Many of the bamboo products are taxed under the GST regime, at par with similar products having origin in wood. Since use of bamboo serves to substitute the use of wood, thus helping in reduced extraction of trees and promoting environmental benefits, the bamboo products should be either exempted or taxed at a level much lower than that of the wood based products.

Bamboo sheets and other products used in housing can replace the highly energy intensive and not so environment friendly products such as, asbestos, aluminum, galvanized iron, fibre-reinforced plastic, plywood, etc., and therefore should be taxed at rates lower than those products, to encourage the use of these eco-friendly products.

12.6.5 Interventions to encourage export of bamboo products

Export oriented bamboo based industries should be set up, especially for bamboo shoot processing and canning, bamboo charcoal briquette manufacture, and bamboo flooring which have export potential. In bamboo rich areas, Special Bamboo Export Processing Zones can be set up, for primary processing as well as production of export oriented goods of bamboo.

The bamboo products with export potential should be given concessional rates of export duties, as these are highly labour intensive, and have potential of creating large-scale employment at local level. At the same time, the import duties on goods that are competing with the local products of bamboo (such as imported agarbatti sticks) should be increased, to favour the locally-produced goods.

Since the bamboo based economy has many players right from the stage of cultivation to manufacture, marketing, export, etc., close tie-up among the various government agencies is required. They should ensure synergy among the production, utilization and marketing of bamboo, so that all the stakeholders are benefitted. Particularly, lack of skills has been found to be an important bottleneck in the efficient utilization of bamboo and therefore, greater role is required from the Ministry of Skill Development, to improve the skills of artisans and other workers engaged in manufacture of bamboo products. The other wings of the government dealing with textiles, industries, forestry, agriculture, food processing, etc, need to come together in promoting bamboo.

12.6.6 Mobilisation of capital and industry

The industry has to play the most crucial role in the development of bamboo sector. Industrialists must be invited and encouraged to invest capital, import/manufacture tools and machinery, set up industrial clusters as well as individual units, and participate at all suitable levels in the value chain. To begin with, pilot projects should be launched by the Government in different regions of India integrating bamboo producers, primary and secondary processing units, skill development centres, research and technology institutions, markets and all other players in the value chain. Land, raw material, infrastructure, credit, subsidy, policy regime and all other requirements of the industry should be addressed through a speedy and transparent system. The bamboo industry should be accorded tax concessions and other incentives similar to the khadi industry.

CHAPTER - 13

SKILL DEVELOPMENT

13.1 Introduction

Skill development can be defined as enhancement of the ability acquired through training and capacity building to carryout activities with enhanced competence. In reference to the bamboo sector, it refers to enhanced competence for employability at every level of the value chain from production to retail. Shortcomings in skill development and capacity building programmes are often the biggest bottlenecks in the growth of forestry sector, especially the bamboo sector. Skill development in bamboo can be the vehicle by which the industry and the community can be integrated profitably since bamboo generates large-scale rural employment in the management of bamboo forests, harvesting, collection, transport, storage and processing.

The basic bamboo processing skills are already available due to the prevalence of traditional bamboo working in India. However, for higher level employment opportunities and quality products generation, both skill development and enhancement of both rural and urban workers is imperative. Bamboo has grown from the 'poor man's timber' to 'green gold' and now to 'greenest of the green material'. It is one of the most fashionable materials and is in great demand across the world for various purposes such as buildings, interiors, bridges, bio-energy and fabric. While the traditional bamboo skills range from handicrafts to low-cost building material (Manjunath and Rao, 2015).

Bamboo is an important resource available in most parts of India. It has been a natural capital for the rural people, especially those in the forest fringes, providing them food and livelihoods. Bamboo thus, can act as a tool for sustainable economic development for the rural and tribal communities, providing them with sustainable income opportunities. Bamboo has potential to generate large-scale rural employment and income through bamboo forest management, harvesting, collection, transport and processing. However, bamboo sector suffers from the danger of fast disappearing traditional skills as younger generation is moving away from the traditional not so remunerative professions including bamboo working to higher income jobs in the towns and cities.

Skill development and consequent high quality production of bamboo products has potential to reverse migration considerably. Traditional bamboo skills need to be infused with the modern designing, value addition processing, preservative treatment against bio-deterioration and suitable finishing for improved functionality and aesthetics. Comprehensive and structured skill development programmes in various techniques and technologies related to bamboo should establish a strong link among the growers, researchers, industry, artisans and other stakeholders.

The efficiency and the technical knowledge of traditional bamboo artisans need to be improved significantly to enable them to be competitive in the wake of the threats from modern materials and products. The employment opportunities for both rural and urban workers could be enhanced with organised skill development activities for mass scale industrial use of the bamboo. This is required also to meet the demand for the handicrafts and other products in local to regional, national and global markets. Over time, peoples' preferences have also changed from traditional to contemporary and from decorative to utilitarian use of bamboos.

13.2 Skill Development and Training Needs

The bamboo sector is an important area, which can be linked to the Pradhaan Mantri Kaushal Vikas Yojana (PMKVY) of the Govt. of India. This flagship programme of the Govt. of India operates at two levels, *viz*., enabling the youth to take industry relevant skill training for better livelihood opportunities as well as enable the individuals with prior skills to be assessed and certified in the identified fields. The scheme, aiming to benefit 10 million youth in 4-year span (up to 2020), is implemented through National Skill Development Corporation (NSDC). The main objectives of the scheme match well with the requirements of the bamboo sector. The upgradation of skills, quality assurance, development of market mechanisms and linkages among the stakeholders are the primary requirements for the development of the bamboo sector (Fig. 13.1).

Organizations such as ICFRE and Indian Plywood Industry Research and Training Institute (IPIRTI) have developed technologies which are extended to the stakeholders through limited number of training programmes. With the support from NSDC, a larger number of people can be trained in technologies ranging from propagation, harvesting and processing to value addition and development of products. Lot of research has already been done by various institutions in the sector, but the percentage of the findings reaching the industry or artisans is very limited. The need is, therefore, to focus on inclusive and balanced growth of the bamboo sector with higher level of skills for all stakeholders.

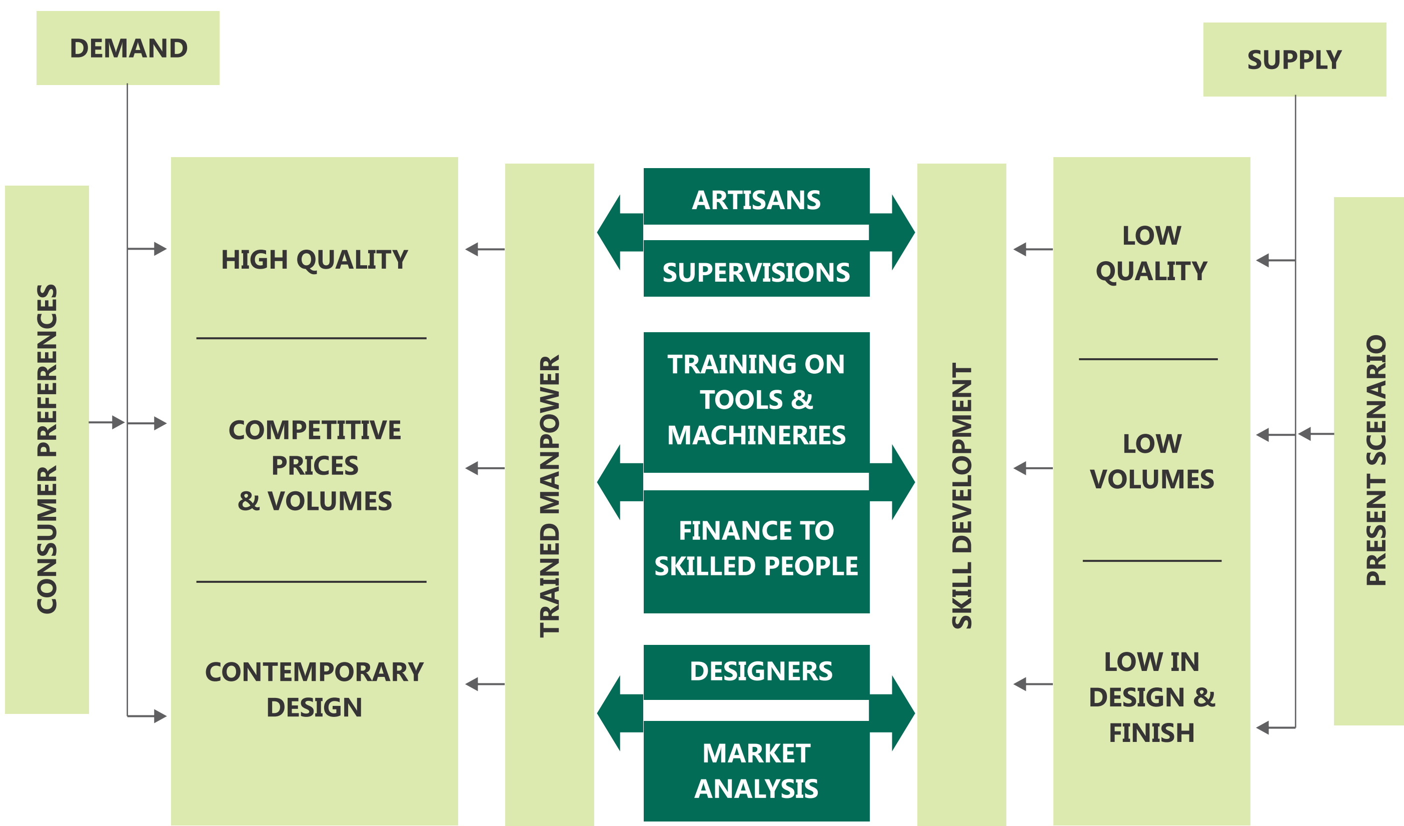

Fig. 13.1: Skill development linkages with supply and demand (Manjunath and Rao, 2015)

The skills of the farmers, processors and the artisans need to be upgraded from time to time for better quality and higher level of products generation with minimum cost. Farmers should also be encouraged and motivated to go for cooperative bamboo farming system and for establishing the primary processing centres. A healthy benefit-cost analysis is a must for the long-term involvement of the farmers. Once bamboo farming is remunerative, farmers themselves will take lead in bamboo business. The current system of demand and supply assessment and market appraisal is full of flaws and is responsible for low level of progress made by National Agroforestry and Bamboo Mission.

In the skill development programmes of the bamboo sector, the economic benefit to the people, especially at the lower levels, is very important. There has to be efficiency benefit as well, which has to be brought through better quality and innovative training programmes. The skill development will need to connect with the industry and demand, and curricula will have to be developed accordingly. It is one of the most important activities required at all levels of bamboo resource development, management, utilization, value addition, marketing and industry. Adequate pool of skilled and trained manpower needs to be developed for achieving faster growth in the bamboo sector. Some of the areas and aspects where skill development is essentially required are listed below in Table 13.1:

Table 13.1: Target areas and groups for skill development

S. No	Areas requiring skill development	Target group	Institutions
	A. Bamboo resource management		
1.	Bamboo clump management and productivity improvement in forest areas	Officials of the forest departments in government owned forests and public in the community owned forests	ICFRE KFRI SFDs
2.	Bamboo selection and mass multiplication	Officials of the forest department, bamboo nurseries	
3.	Bamboo propagation and nursery management	Officials of the state forest departments, private bamboo nurseries	
4.	Bamboo plantation management	Farmers	
5.	Bamboo harvesting	Public in the community owned forests, farmers, skilled labourers	
	B. Bamboo utilization		
6.	Bamboo preservation treatment	Bamboo preservation industries	ICFRE IPIRTI NIDs ITIs
7.	Bamboo handicrafts	Artisans	
8.	Bamboo in construction	Architects and engineers, skilled labourers	
9.	Bamboo in furniture	Carpenters, furniture makers	
	C. Bamboo value-addition and marketing		
10.	Bamboo charcoal making and briquetting	Entrepreneurs, businessmen, public in the community owned forests, farmers	ICFRE CBRI CFTRI IITs ITIs
11.	Novel bamboo food products, viz., bamboo vegetable, pickle, vinegar, wine, etc.	Agro-processing industries, public in the community owned forests, farmers	
12.	Bamboo use in house construction, bamboo reinforcement	Engineers, architects, skilled labourers	
13.	Bamboo processing tools handling	Artisans, workers, technicians, entrepreneurs, businessmen	
14.	Wooden bamboo products manufacturing	Workers, technicians, supervisors, entrepreneurs, businessmen	
	D. Product diversification		
15.	Composites and modified products	Workers, technicians, supervisors, entrepreneurs, businessmen	ICFRE IPIRTI NID
16.	Design Interventions	Engineers, architects, designers, supervisors and technicians	
	E. Market linkages and entrepreneurship		
17.	Bamboo products marketing	Entrepreneurs, managers and industrialists	IIMs, IIFM

If Indian bamboo development effort and trade has to touch the heights attained by China then country has also to gear up for effectively enhancing the skills of the above target groups (Figs. 13.2 and 13.3). The present institutional mechanism almost totally ignores bamboo as a sector with great potential. Bamboo skill development centres should be included in every cluster/bamboo bearing district. The existing research and training institutions should be strengthened. Curricula and illustrated lecture materials may be developed for 2-month Certificate and 6-month Diploma Courses initially twice a year (but not limited to). Each of these courses should have sufficient seats for quality training of personnel from the targets group. Bamboo application technology courses of short to long durations would also be a must to generate a highly skilled manpower in the bamboo sector.

Fig. 13.2: Installation and testing of bamboo processing machines at the CFC in Punjab

A beginning has been made by Tripura University, which organises Post-Graduate Diploma and Certificate courses in Bamboo Cultivation and Resource Utilization. The total absence of awareness on bamboo as a building material among architects and engineers can be addressed through establishment of specialised courses and project work in research, technology and training institutions. The skilled manpower minimises the wastage and turns out aesthetically designed, high quality and durable products. Also productivity of trained manpower is always higher compared to unskilled ones. Bamboo sector has potential to provide self-employment and livelihood to rural poor including those living in and around the forests.

Fig. 13.3: Demonstration-cum-hands-on exercise with bamboo primary processing machines during Hornbill Festival at Kohima, Nagaland in December, 2016

The need for skill development of the involved people in land preparation for bamboo cultivation, germplasm conservation, bamboo quality rating, plant production, inventory and harvesting, preservation and stocking is also required for bamboo sector development in the country. China has effectively implemented its bamboo skill development programme to become the largest global bamboo exporter and foreign exchange earner among all nations of the world.

CHAPTER - 14

LESSONS FROM OTHER COUNTRIES

14.1 Introduction

Over the last three decades, China has achieved an extraordinary accomplishment in transforming its bamboo sector by tapping the vast potential of bamboo. This has remarkably contributed to industrial and economic growth and improvement of environment and livelihood over large areas in China. The experience from China has shown that under right conditions, bamboo can be a lead sector for rural industrialization and large-scale poverty reduction. This exemplary effort now serves as a model for several countries to emulate. Lessons from China and other countries have been reviewed in this chapter drawing largely from examples in published studies, especially by Marsh and Smith (2007).

14.2 China

Bamboo industries have been a key driving force in rural industrialisation and widespread poverty reduction in many counties in China. The benefit has been dispensed over a very large population in bamboo regions, with average household incomes for the population increasing by 220 per cent in the first ten years of the bamboo boom in Anji county, Zhejiang province, one of China's ten “bamboo homelands”.

14.2.1 Special features

Several features were crucial to the dynamic growth of the bamboo sector in China in general, and Anji in particular (Marsh and Smith, 2007):

(a) At industrial level, technical and supply chain innovations led to the development of a robust pre-processing step in the value chain of bamboo. At, or near-source, pre-processing workshops with specialized but simple machinery separate bamboo culms into various parts and direct these parts into different supply chains. Primary and secondary processing units specialise in specific steps of pre-product processing, and finally supply semi-finished product to the specialised final manufacturer. This creates industry-wide efficiency and greater value-adding at the local level.

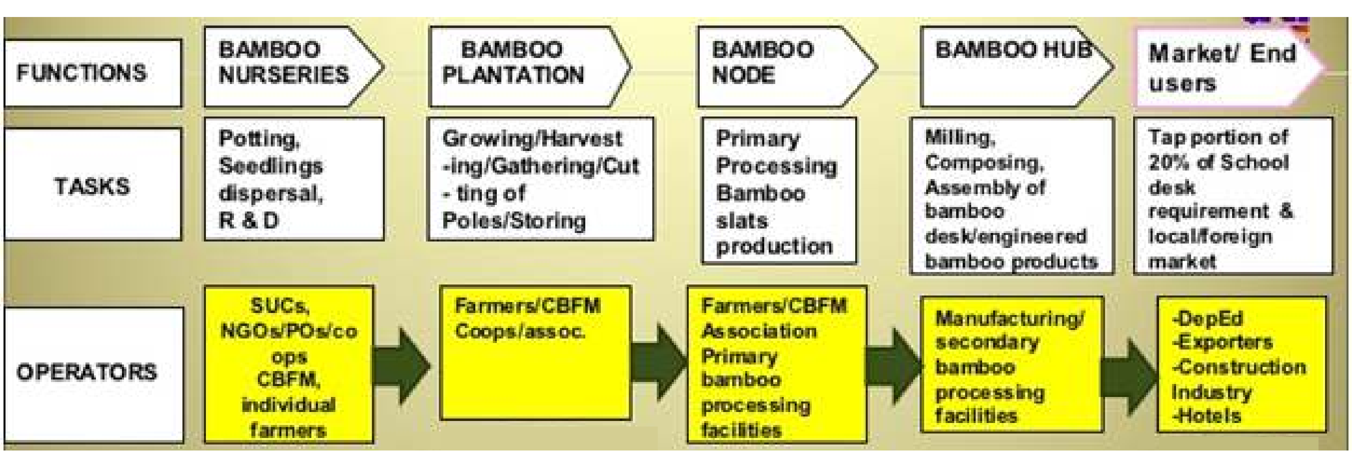

Fig 14.1: Value chain of bamboo in China

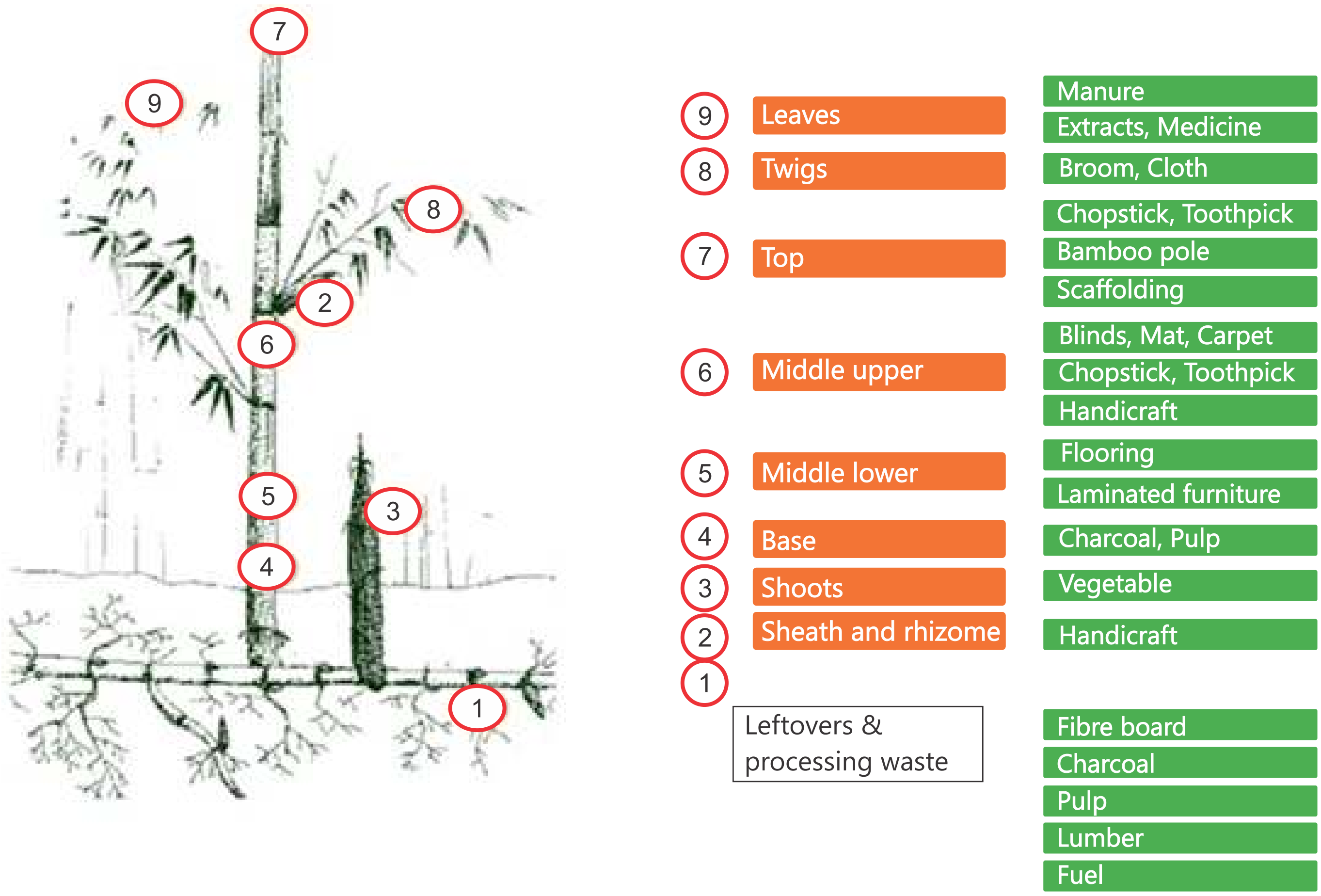

Fig. 14.2. Different parts of a bamboo plant are used to manufacture different products (Source: http://satoyama-initiative.org/wp-content/uploads/2012/08/Fig26.jpg)

(b) Strong demand and favourable market conditions:

- Located close to the major cities, viz., Shanghai and Hangzhou, Anji is ideally located to meet market demand.
- China's logging ban in the 1990s created additional demand for timber substitutes and led to a 10 per cent -15per cent jump in bamboo prices over a single year,

(c) Consistent support of the Chinese Government targeted the development of the bamboo sector as part of economic development planning,

(d) Concurrent development of processing industries and bamboo resources created a demand for farmers' products, increasing value-addition and capital in the local economy, as well as reinvestment and diversification of income opportunities,

(e) Local development of specialist processing technologies and equipment ensured appropriate, affordable equipment was available,

(f) Minimum scales of production suited to the resources of farmers, small and medium enterprises (typical area of bamboo in Anji was 0.6 ha per household),

(g) Lower perceived market risks due to diversity of uses of culms and shoots, leading to greater attractiveness of bamboo for farmers and processor, and

h) A readily available existing bamboo resource and a tradition of growing bamboo enabled exploitation of emerging market opportunities.

In addition, there were four pre-requisite policy reforms that paved the way for the rapid development of the bamboo sector in China and will also be an important consideration for the Mekong countries.

(a) Land tenure systems: Clear land ownership and usage rights, characterized by 30-50 year land leases that allows for the transfer of rights to family and others.

(b) *Supportive business environment:* creating the conditions for a vibrant private (and collective) sector, especially small and medium enterprises.

(c) Market liberalization: Opening up of the economy to allow access to international markets and investors.

(d) Both bamboo culms and shoots are traded in open markets, being one of the first forest products in China to be exempted from State marketing board control. Market intermediaries, agreements between farmers and large bamboo processing firms and even incipient futures markets can be found in different regions (Ruiz Pérez, *et al.*, 2004).

The variable scale and diversity of processing units and the possibility of a degree of pre-processing by farmers makes local processing a viable option. Bamboo epitomizes the rural value-adding industrialization approach which has been promoted in many parts of China, while its diversity of uses allows for a certain degree of county-level spatial specialization (Ruiz Pérez, *et al.*, 2004). At the local level, several other favourable developments took place:

(a) Heavy public investment in the development and dissemination of local processing technologies greatly increased their affordability and accessibility to local enterprises.

(b) Intensification of raw material production with yields rising to 8.9 tonnes per ha from 4.9 tonne per ha between 1978 and 1998. The area of bamboo cultivation increased by 16 per cent while production of culms increased by 98 per cent.

(c) The revolution in industrial bamboo practices permitted easy transportation and brought about waste handling savings. The potential for 100 per cent utilization rates (Fig. 14.2) was achieved in this model thereby achieving maximum resource utility. Business, research institutes and government all contributed to the technology development driving this innovation.

(d) Bamboo shoot production generated sufficient value for farmers to be a stand alone industry driving poverty reduction, but it also provided opportunities for diversification for bamboo farmers.

The revolution in industrial bamboo practices permitted easy transportation and brought about waste handling savings. The potential for 100% utilization rates (Fig. 2.) was achieved in this model thereby achieving maximum resource utility. Business, research institutes and government all contributed to the technology development driving this innovation.

Bamboo scrimber:

Bamboo scrimber is a novel structural bamboo composite commercialized in China in the beginning of the century. In scrimber or strand woven bamboo, bundles of crushed bamboo strips are compressed into panels or blocks that form basis for panels, beams, flooring, etc. It can be produced with small diameter bamboo at utilization rate of over 90 per cent. Scrimber has improved water absorption and swelling behaviour, allowing application to outdoor landscaping, exterior decoration, and garden furniture. Scrimber processed at 0.35 MPa saturated steam treatment showed excellent mechanical strength, which is favourable for structural application.

Markets for bamboo can be grouped into 'traditional' and 'non-traditional' or 'emerging' markets. Demand remains strong in traditional markets such as handicrafts, blinds and bamboo shoots with profitable opportunities despite moderate growth. Other traditional markets, such as chopsticks, are highly commoditized with low growth and low profit margins. Emerging bamboo markets include flooring, building products and laminated furniture. These represent the largest growth opportunities for bamboo. Additional niche market exists for charcoal. Supply problems, including the high demand for certified timber, create a positive market outlook for bamboo. Overall prospects for a diversified bamboo sector look strong.

14.2.2.1 Handicrafts

Very high rates of pro-poor financial impact and employment creation per hectare of bamboo are seen due to the highly manual processing of relatively small volumes of bamboo, with most benefit gained by small-scale processors and factory workers. This supports the argument that handicrafts are a distinct sub-sector, based on the sale of skilled craft labour rather than of large volumes of bamboo material.

14.2.2.2 Bamboo shoots

Deliver high levels of pro-poor financial impact per ha due to the higher prices and yields of shoots compared to culms. In this sense, shoots are a high value agricultural crop. However, shoot farming creates relatively little employment. Most of the financial benefits are retained by farmers themselves and not distributed along the supply chain.

14.2.2.3 Industrial processing

From a pro-poor perspective, three distinct industry groups emerge within the industrial processing sub-sector: Low-value and bulk; medium-value; and, premium processing :

- Low-value and bulk processing industries, such as charcoal, paper and pulp, have low rates of both pro-poor financial impact and employment creation. They achieve only marginally higher levels than selling unprocessed raw bamboo culms to the construction industry. This lower impact is partially offset by the fact that the industry can utilize low quality bamboo, leftovers and processing waste from other industries and various species.
- Medium-value processing industries, such as chopsticks and mat boards (panels), create similar levels of employment as the premium processing industries but only half the pro-poor financial impact per hectare of bamboo. However, they are able to use lower grades of bamboo than premium processors.
- Premium processing industries, such as flooring, have the highest rates of pro-poor financial impact and employment creation of the industrial processing industries, but require premium quality bamboo. Their rate of economic impact is twice the level of the medium-value processors and five times the level of the low-value and bulk processors. Similar results are demonstrated in China for laminated furniture industries.

Much of the growth in bamboo sector is expected to come from the non-traditional segment of bamboo products including laminated furniture, flooring and panels.

Characteristics of advanced engineered bamboo materials :

Advanced bamboo engineered materials are significantly different from the existing bamboo composites with the following characteristics:

High stiffness: $\geqslant$20 GPa

Strength: $\geqslant$ 200 MPa

Fatigue strength: Residual strength$\geqslant$ 50% after 1 million cycles

High size stability: $\leqslant$5 % in thickness expansion after two cycles of water boiling for 3 hours and drying 1 hour.

Higher added value: Net profit $\geqslant$30%

Used in high-end fields: Wind blade, cars, yacht etc.,

Small variation in properties: CV $\leqslant$8%

14.2.3 Economic development and benefit distribution

The domestic bamboo sector in China is now worth US$ 19.5 billion per year and provides employment to 7.75 million people (INBAR, 2014). The benefit has trickled fairly well to all sections of the society engaged in bamboo value chain.

The term "pro-poor financial impact" describes the local component of total revenue that is captured by poor communities. Bamboo resources and labour together typically represented approx. 80% of the total cost of production for most bamboo processing industries with profit margins of approx. 7 per cent (ranging typically from 0 to 12 per cent). At the processor level, approx. 75 per cent of revenue is captured by local costs compared to approx. 7 per cent taken as profits. The notable exception is paper where only 33 per cent of the revenue is captured locally.

Low-value and bulk processing industries, such as charcoal, paper and pulp, have low rates of both pro-poor financial impact and employment creation. They achieve only marginally higher levels than selling unprocessed raw bamboo culms to the construction industry. This lower impact is partially offset by the fact that the industry can utilize low quality bamboo, leftovers and processing waste from other industries and various species.

Medium-value processing industries, such as chopsticks and mat boards (panels), create similar levels of employment as the premium processing industries but only half the pro-poor financial impact per hectare of bamboo. However, they are able to use lower grades of bamboo than premium processors.

Premium processing industries, such as flooring, laminated furniture, etc. have the highest rates of pro-poor financial impact and employment creation of the industrial processing industries, but require premium quality bamboo. Their rate of economic impact is twice the level of the medium-value processors and five times the level of the low-value and bulk processors.

Table 14. 1 indicates this differentiation across products. Premium products require high value raw bamboo (species, culm size and quality) creating farmer income. They also create more jobs in the supply chain. But only certain parts of the culm can be used for premium products, so the value from premium products can only be realized through the development of an efficient mixed industry which is maximizing the utility of all parts of the plant. The critical factor to establishing a mixed industrial sub-sector is the presence of near-source pre-processing workshops which process bamboo culms into various parts (including waste), which are then transported to other factories for secondary processing (into paper, blinds, flooring, etc). This innovation in the supply chain structure enabled China to reduce prices and enter a range of new product markets.

Table 14.1: Efficiency of impact of bamboo industry supply chains in China

Industry segment	Overall financial output (US$ per ha)	Pro-poor financial impact (US$ per ha)	Job creation (FTE[1] per ha)	Total benefi-ciaries (Farmers+ workers per ha)	Local costs (% of total costs)	Women in supply chain (% FTEs)	Jobs in rural comm-unities (% FTEs)
Handicrafts	14,3000	11,300	39	40	85	60	95
Bamboo shoots	3.800	3,100	0.4	1.1	90	31	100
Flooring	3,100	2,400	1.2	1.9	85	49	35
Chopsticks	1,600	1,300	1.1	1.8	85	49	46
Woven mat	1,100	1,000	0.9	1.5	100	42	100
Mat board	1,300	810	0.8	1.5	70	46	98
Charcoal (briquettes, China)	600	420	0.2	0.9	75	37	95
Charcoal (briquettes, Lao PDR)	320	180	0.3	1.0	60	38	79
Paper + pulp	1,500	490	0.3	1.0	35	38	66
Raw culms	360	360	0.1	0.8	100	31	100

(Source: Marsh and Smith, 2007)

[1]FTE: Total number of Full Time Equivalent (FTE) jobs created in farming, pre-processing, secondary processing and associated activities such as transport and loading, trading and wholesale.

14.2.4 Raw material supply

China has been able to attain this marvellous growth of bamboo sector despite having less bamboo area (5.44 million ha in China versus 11.36 million ha in India) through greater removals (1230 million tonnes in China versus 14.62 million tonnes in India). The total growing stock of China and India are 164 and 122 million tonnes (Lobovikov *et al.*, 2007).

14.2.5 Green development

A key variable in the resource scenario is the sustainable yield per ha of bamboo. In Anji, China, in 2003 the maximum yields achieved by farmers were around 14 tonnes per ha per year of Moso. Average yields across China are around 9 tonnes/ha. The bamboo resource base has increased steadily since the start of this approach, both in surface area (32 per cent) and in density of stands (41 per cent). The combined expansion of plantations and increased density of stands has resulted in an exponential increase in output of bamboo culms and shoots (590 per cent and 1050 per cent respectively) that contrasts sharply with the stagnant and recently decreasing output of timber (Ruiz Pérez, *et al.*, 2004).

14.2.5 Emerging lessons

Recent developments that have contributed to the growth of the industry while also presenting new challenges:

- emergence of a pre-processing industry, which greatly assists in achieving very high value-added utilization rates of the bamboo harvested,
- "Nieyou" a traceability system in Anji allows for easy identification of the age and source of culms and is linked to harvest quotas and regulated by the Forestry Bureau. It has the potential to form the basis of an effective "Certification" or "Chain of Custody" system,
- quality is becoming an increasingly important requirement in the global market. Anji, and China as a whole, have not yet established a reputation for providing this,
- raw material shortages and rising bamboo prices (US$ 85 per tonne for "moso" culms in early 2006) are squeezing profit margins and limiting the output of individual businesses that are unable to secure enough raw material, and
- decreasing profit margins and excessive competition in several markets have driven the increasing commoditization of some products

14.3 Vietnam, Lao PDR and Cambodia

In order to embark upon plans for rapid growth of bamboo sector in Mekong countries comprising Vietnam, Lao PDR and Cambodia, a feasibility study was carried out (Marsh and Smith, 2007). The average yield of bamboo is approx. 9.5 tonne per ha per year ("luong" bamboo) in the active bamboo processing areas of the Mekong countries. Clear market growth opportunities coupled with appropriate conditions in the Mekong countries offer opportunities to access the growing global bamboo markets.

Table 14.2: Efficiency of impact of bamboo industry supply chains in Vietnam, Lao PDR and Cambodia

Industry Segment	Mekong potential towards capturing a greater share of growing world markets					
	Pro-poor financial impact (US$ millions)	Financial output (US$ millions)	Employment creation (FTE)	Total direct beneficiaries (People)	Area of bamboo (ha)	World bamboo market (US$ millions)
Handicrafts	266	336	9,20,000	9,36,000	24,000	4,200
Bamboo shoots	111	136	16,000	41,000	36,000	1,700
Wood furniture	217	280	1,06,000	170,000	90,000	5,600
Wood flooring	46	60	23,000	36,000	19,000	1,200
Wood panels	100	110	68,000	1,27,000	85,000	2,200
Blinds	47	60	41,000	44,000	4,000	1,200
Chopsticks	16	20	14,000	23,000	12,000	400
Charcoal	5	7	1,000	2,000	11,000	130
Activated carbon	6	9	1,000	3,100	18,000	170
Paper/pulp	35	110	18,000	69,000	72,000	n/a
Raw bamboo	60	60	24,000	1,41,000	1,67,000	n/a
Total	**909**	**1,185**	**12,32,000**	**15,92,000**	**5,38,000**	**16,830**

(Source: Marsh and Smith, 2007)
The industry is separated into three independent sub-sectors: handicrafts, bamboo shoots and industrial processing.
At a sub-sector level, the analysis leads to the following conclusions (Table 14.2)

- Handicrafts are the most important source of employment creation, accounting for more than 75 per cent of all employment in the sector under both scenarios. The pro-poor financial impact of handicrafts is substantial though they deliver relatively minimal benefits to farmers.
- Bamboo shoots represent the smallest of the three sub-sectors, but its high financial impact rate means that it provides 10-20 per cent of the pro-poor financial impact from employment rates of just 1-2 per cent.
- Industrial processing emerges as the largest sub-sector in terms of pro-poor financial impact, accounting for up to 60 per cent of the total pro-poor financial impacts of the sector. The sub-sector also consumes by far the largest share of bamboo (over 85%) and so is the most important sector for delivering large-scale benefits to poor farmers.

14.4 Philippines

14.4.1 Achievement

The Philippine Government directed the use of bamboo for at least 25 per cent of the desk and other furniture requirements of public elementary and secondary schools.In 2010, the Philippine bamboo industry was formalized through Executive Order that created the Philippine Bamboo Industry Development Council (PBIDC). It prioritized the use of bamboo for furniture, fixtures and other construction requirements of government facilities. In 2011, US$ 4,24,872 worth of bamboo handicrafts, including baskets and basketware, containers, purses, handbags and wallets, were exported (Aggangan, 2015).

The Philippine Government directed the use of bamboo for at least 25 per cent of the desk and other furniture requirements of public elementary and secondary schools.

14.4.2 Strategies and Action Programmes

a) Nursery/Plantation Establishment

1. Establishment of 100 thousand hectares of new plantations of bamboo
2. Plans to produce two million plants by 30 to 40 strategically located nurseries
3. Training programmes on bamboo propagation (both conventional and modern methods), proper planting, maintenance and harvesting
4. Worked out areas of bamboo plantations needed for different end uses in the Philippines

b) Product development

1. Furniture, handicrafts and engineered bamboo are the focus for product development targetting local and foreign market
2. Micro- to small-scale engineered bamboo plants have been established.
3. Engineered product from flattened bamboo using the FPRDI-developed bamboo flattening machine has been found comparable to premium hardwood lumber.
4. Research and development on
   - Cheap adhesives, preservatives, binders (for charcoal briquettes), and finishing chemicals from local species of plants.
   - economical methods of drying and preservation
   - product development and processing of lesser-used species of bamboo
   - processing tools, equipment and machineries
   - rayon and cellulose derivatives
   - more engineered bamboo products

14.5 Malaysia

The bamboo industry in Malaysia is quite primitive, mainly as a cottage industry, with low returns. To boost the bamboo sector, Malaysia has hired the services of Kanger International Berhad, a Chinese company, engaged in the research, development, manufacture and trade of bamboo flooring and related products. It specialises horizontal and vertical bamboo flooring products; and strand-woven and related products, as well as bamboo wall panelling products, bamboo doors, and bamboo furniture products.

The company will work with Forest Research Institute, Malaysia (FRIM) from 2017 to 2020 towards development of a high-value bamboo industry in Malaysia with the aim of making bamboo a significant sector of the economy. The cooperation includes establishment of bamboo plantations on a commercial scale in Malaysia, sale, marketing and use of bamboo, research and development to improve bamboo products, manufacturing processes and new uses/ products, and technical and financial data to support the above activities. It will leverage on Ranger's international sales network and experience in the bamboo industry to develop it as a new economic sector in Malaysia.

14.6 Kenya and Sub-Sahara Africa

There are about 1,50,000 ha bamboo forests in Kenya, partly pure and partly in mixture with trees and shrubs. Bamboo in Kenya play a very important role in fencing, house construction, water harvesting, cottage industries dealing with matchsticks, baskets, tooth-picks, various other handicrafts and, in agricultural farming especially for supporting horticultural crops (Kingomo, 2017).

Bamboo products are gaining ground in Kenya and farmers are now focusing on forming part of this wave. Equipping farmers with bamboo planting and maintenance skills, teaming up with the private sector for processing and value addition are major challenges facing the adoption and eventual growth of bamboo sector.

GreenPot Enterprises, a fully integrated agroforestry outfit, is helping to build the new industry. A sum of KSH 5 billion (Rs. 316.69 crore or US$ 48.38 million) is now going to be invested by the company (Akumu, 2017). GreenPot plans to set a number of factories in diverse parts of Kenya. The first factory is set to be completed by 2017. The proposed factories will produce the following products: Construction, flooring, block boards, veneers, timber-substitutes, briquettes, pellets, textile industry.

The company has selected three main varieties of bamboo—moso, giant bamboo and Dendrocalamus membranaceus because they are highly suitable for the chosen areas and have more economic viability than other varieties.

The new partnership with bamboo farmers is aimed at boosting economic livelihoods and fostering 'green development'.

It is widely believed that planned and sustainable utilization of bamboo forests is feasible and would go a long way in providing self-employment and job opportunities to the rural population, apart from being instrumental in bridging the gap between requirement and availability of indigenous raw-material for industry. The later use of bamboo has however not been developed, not only in Kenya but also in the entire Africa.

Sub-Saharan Africa comprises 48 countries, including Kenya, and has three million hectares of bamboo forest which is around four percent of the continent's total forest cover. Projects similar to Kenya are expected to be launched in other parts of Sub-Saharan Africa too.

14.7 Australia

Australia has sizeable area where bamboo can be planted for domestic and international market. It is planning to embark upon largescale cultivation of bamboo to be backed by industrial utilisation.

A very important inference from analysis of the bamboo sectors of China and other countries is that raw material stock and research backup in India are good enough to speedily move towards development of a strong bamboo industry. The need for specialised tools and machinery, which may be manufactured by India's domestic companies in due course of time, can be initially met through imports.

14.8 Conclusion

Some specific lessons that emerge from the review of other countries are:

- India needs massive investment and participation of private manufacturing industry in the bamboo sector.
- Technology is already available to undertake large manufacturing operations.
- Adequate bamboo stock is available in the country. In fact India has the largest bamboo area and second largest growing stock (74 per cent of China) in the world, to support the bamboo industry. The availability of raw material, which is quite low at present due to management/policy issues, is bound to improve dramatically with harvests at silvicultural rotation.
- Bamboo industry will bring about pro-poor and inclusive development.
- Necessary policy initiatives require be taken at appropriate level to support the bamboo industry.
- Immediate and vigorous steps require to be taken by India to tap the potential and establish hold of Indian bamboo industry in the world market considering the rapid strides being taken in bamboo sector by other countries, particularly in Asia and Africa.

Transferring resource development, industrial supply chain development, and technological and management experiences from the global market leader, i.e. China, is necessary and achievable as an important driver of the bamboo sector in India. Appropriate, targeted support is needed to create progressive business environments and to ensure financial viability and good returns on investment for tribal and rural communities, processors, manufacturers, traders and all others in the supply chain. This will help expand the success of the supply chain, create substantial pro-poor income, and create hundreds of thousands of new jobs in India.

SECTION-IV
RECOMMENDATIONS

RECOMMENDATIONS

A detailed review of the bamboo sector in India, diagnosis of its constraints, analysis of opportunities and learnings from other countries led to the identification of various measures that can help improve the performance of this sector in India. The recommendations are as follows. The para numbers in parenthesis indicate the chapter-wise locations of the particular recommendation

Issue	Recommendations
A. Sustaining Supply of Raw Material	
1. Expanding cultivation	1. Bamboo species should be prioritised on the basis of their use, demand and supply for undertaking large scale plantations for future industrial and other needs[Para: 4.7.1, 6.7] 2. En-masse plantations of bamboo must be promoted in private lands, community lands and wastelands [Para: 4.10.2, 12.6.1] 3. The Government should consider leasing out the Non-forest government /revenue/ lands, presently devoid of tree cover, to panchayats, communities, bamboo-based industries, or forest corporations for raising bamboo plantations [Para: 4.10.2, 12.6.1] 4. Land adjoining the national highways, railways, rivers and canals should be used for raising bamboo, with the help of local people, wherever feasible by providing incentives. [Para: 4.10.2, 12.6.1] 5. Bamboo planting , either alone or with horticultural crops, should be encouraged to be undertaken in private lands not fit for agriculture [Para: 6.7, 12.6.1] 6. The bamboo based industries should be encouraged to adopt contract farming either by planting bamboo on farmlands under long term lease or providing inputs for bamboo plantation and buying produce through a buy-back arrangements. [Para: 6.7, 12.6.1] 7. Large bamboo nurseries of priority species should be established in the bamboo growing areas by the SFDs, forestry research organizations, industries, NGOs, communities and individuals, to ensure production of quality planting stock. [Para: 4.10.2, 5.8, 6.7]
2. Improving productivity: Silvicultural interventions in government-owned forest areas	8. Degraded forest areas ought to be planted with suitable bamboo species, wherever possible depending upon ecology, suitability, socio-economic relevance and commercial feasibility [Para: 4.10.1] 9. Assisted natural regeneration and enrichment planting with nursery-grown quality seedlings ought to be undertaken to augment the bamboo resources in the pure and mixed bamboo forest areas. [Para: 4.10.1]

Issue	Recommendations
A. Sustaining Supply of Raw Material	
	10. In year of gregarious flowering, superior clumps should be identified for retention and collection of seeds and larger population of clumps should be extracted before seed set. The seed of such superior clumps should be used for regeneration of the forest [Para 4.10.3] 11. Intensive and participatory approach to protection and management must be done for bamboo forests with active participation of local communities to reduce theft of bamboo culms and prevent unscientific culm removal by contractors [Para: 4.10.3] 12. Grazing must be effectively controlled/ regulated in bamboo areas, especially during times of bamboo regeneration and new culm emergence. [Para: 4.10.3] 13. Bamboo should be harvested at silvicultural rotation as applicable to respective species and sites so as to realise higher productivity. [Para: 4.4] 14. Protocols for raising, managing and harvesting bamboo from forests and plantations, which are already standardized, should be implemented [Para: 4.10.1]
3.Improving productivity through genetic interventions	15. Multiplication of promising/ potential higher productivity stock, already available with research organizations, must be started immediately by adopting the approach of multi-step selection and concurrent multiplication to expeditiously supply such improved quality plants to growers. [Para: 5.7] 16. Improved planting stock of clonal origin should be used to the maximum while establishing new plantations to ensure for uniformity of the raw material, easy harvest and higher productivity [Para: 5.7.2] 17. Seed orchards can be raised for species that flower sporadically in order to ensure increased supply of quality seeds, by raising blocks of plantations of known seed year, in a series [Para: 5.4.2]
4.Increasing availability	18. All the bamboo forests, including the private and revenue forests, ought to be covered by working/ management plans, approved by the government. The plans should clearly prescribe bamboo management guidelines, harvestable stocks as well as the minimum number of culms to be retained during harvest [Para: 4.4] 19. SFDs must ensure harvest of bamboo at silvicultural rotation to maximise yield for supply to industry [Para: 4.4]. This will also help to reduce fire hazard, disease incidence and other related management problems. 20. Bamboo should be sold at competitive rates, in a transparent manner. Options of non-conventional sale such as through online purchase too must be explored [Para: 5.7.2] 21. Traditional artisans and high value-addition industries (e.g. handicrafts, furniture, structural usage, composites, incense sticks, textile, etc.) should be given Bamboo from forests on a higher priority than low value-addition industries (e.g. pulp and paper, biofuel, etc.), other things being equal. Among high value-addition industries, the highest priority should be accorded to micro-enterprises, followed by small, medium and large enterprises in decreasing order [Para: 7.9.2]
B. Sustaining Demand and Consumption	
1. Market networking and linkages	22. Sale of bamboo products must be promoted through regularly held trade fairs, bamboo expos, bamboo haats, bamboo emporiums, etc. [Para: 6.7, 12.6.3] 23. The Govt must consider greater use of bamboo products in government construction. This

Issue	Recommendations
B. Sustaining Demand and Consumption	
	would give an immediate boost to the high value industry sector. [Para: 6.7, 12.6.3] 24. Procurement of bamboo furniture and other products in offices, educational institutions, rest houses, etc. must be encouraged, at least to the extent of 25 per cent, through orders by the government. The Govt should discourage use of the energy inefficient products such as steel furniture. This would also go a long way in reducing the carbon footprints and promote carbon locking through use of bamboo and wood products. [Para: 6.7, 12.6.3] 25. The use of bamboo-wood, which is a novel product and a substitute for wood, needs to be encouraged by stipulating use in the Public Works Department of both the Centre and the States. [Para: 12.6.3] 26. Bamboo strand lumber, in particular, as an alternative to conventional timber should be promoted as an environment friendly proposition due to the fast renewable and multiple cropped nature of bamboo clumps [Para: 12.6.3] 27. Overseas markets need to be aggressively tapped for sale of finished products. The Govt can consider giving tax holiday for export of finished bamboo products [Para: 12.6.5] 28. Use of bamboo-made pre-fabricated houses must be promoted in earthquake-prone areas. Such houses, often called 'pack-flat' and 'knock-down', can be easily packed in boxes, transported and assembled.[Para: 12.6.3] 29. Use of bamboo ought to be promoted as a structural material in "Housing for All by 2022" Mission of Government of India [Para: 12.6.3]. 30. Bamboo must be included in the schedule of rates, specifications and building codes of the government agencies and PWD and concerned officials ought to be made aware of the advantages of bamboo [Para: 12.6.3] 31. The use of surplus bamboo in pulp and paper industry must be encouraged to reduce the need for import of pulp and create domestic demand. [Para: 6.7, 12.6.3]. As the supply of bamboo through plantations increases, the gap in demand and supply of raw material pulp and paper industry will decrease. 32. Bio-energy is a very fast growing sector and bamboo can contribute immensely in meeting the energy needs. Bio-ethanol production from bamboo should be supported by stipulating compulsory blending with fossil fuels. Bio-ethanol, charcoal briquettes and similar products can form an essential component of bamboo waste utilization. The Government must consider the use as policy matter. [Para: 12.6.3] 33. Awareness programmes of architects, builders, civil engineers should be organised for generation of awareness about bamboo in construction [Para: 12.6.3]. In fact, Bamboo as structural and constructional material should be included in the curriculum of architecture and design courses at university level.
2. Quality standards/ assurance and branding	34. At present, there are no quality standards in place, and the potential customer is not assured of the quality of the products. A specialised agency should be appointed to ensure the quality standards. Product testing and quality control ought to be exercised to increase market acceptability [Para: 7.9.4] 35. Big retail chains can be roped in to promote sale of bamboo-products to high- and middle-income groups in urban centres [Para: 8.12.3]

Issue	Recommendations
B. Sustaining Demand and Consumption	
3. Awareness	36. Product promotion must be undertaken vigorously highlighting the environmental, socio-economic and quality advantages of bamboo product [Para: 12.6.4] 37. A campaign should be launched to promote use of bamboo and its products in domestic market and promoting demand for products of domestic industry in the international market [Para: 6.7, 12.6.3] 38. Linkage should be promoted among raw material suppliers, artisans, pre-processing industries, manufacturers, sellers in domestic markets and exporters and export markets through traditional and digital platforms [Para: 6.7, 7.9.5]
C. Product Development	
1. Networking of industries	39. A cluster approach should be adopted for promoting the networking of various industries. Primary processing units specialising in specific steps of pre-product processing ought to be established near areas of bamboo production. These units must converge into big units doing secondary processing which would, in turn, converge into bigger industries making finished products. This would reduce wastages, promote efficiency and develop expertise in specific steps thereby resulting in a significant drop in cost of production [Para: 6.7, 7.9.1] 40. District or block level clusters should be formed and common facilitation/ technology centres with machinery must be developed [Para: 7.9.3]
2. Product manufacture	41. The industrial units should carry out production in their niche areas to develop expertise. Raw material for their specific requirements should be sourced from respective cluster and produce disposed through the cluster. [Para: 7.9.3, 8.12.2] 42. State-of-the-art technology and innovativeness should be used to develop new products. [Para:7.9.4]. The research and development (R&D) organizations can play a major role in this regard. Already such agencies have developed a number of products/processes/techniques which can be extended to the stakeholders. These agencies can further be supported in their R&D endeavours. 43. Production should be focused towards high-value as well as high-volume goods for domestic as well as export market. New premium products such as bamboo scrimber, bamboo flooring, laminated furniture, etc. should be produced by the industry. [Para: 8.12.2] 44. New types of 'pack-flat' and 'knock-down' products ought to be promoted for cheap transport [Para: 8.12.2] 45. Mechanisation /semi-mechanization should be done in handicraft, agarbatti stick and furniture industries [Para: 7.9.3] 46. Newer product must also be identified and produced based on regular market surveys from domestic and international markets [Para: 8.12.2] 47. Hurdles or problems in any step from procurement of raw material to sale of finished product must be communicated to nodal agency on bamboo (currently NABM) and to ICFRE for addressing the problems [Para: 7.9.5]

Issue	Recommendations
C. Product Development	
3. Increasing scope of bamboo use	48. Armed forces and para-military should be encourage to use innovative bamboo products. The 'pack-flat' and 'knock-down' pre-fabricated houses can be easily transported and dismantled. Such housing units can save a lot of cost on material and transport [Para: 8.12.4] 49. Bamboo bridges in remote areas would also solve a lot of problems of commutation for the rural populace as well as for the armed forces, who often have to construct such bridges at a very short notice[Para: 8.12.4] 50. Organizations such as DRDO, IPIRTI and ICFRE must collaborate to develop such products. A policy directive in this regard by the Govt is most essential [Para: 8.12.4]
3. Trained manpower	51. Trained bamboo entrepreneurs must be supported under the "Startup India" programme of the Government of India to venture into bamboo entrepreneurship [Para: 7.9.6] 52 The industry should get their workers trained at institutions specialising in bamboo processing and product manufacturing [Para: 7.9.6]. Bamboo furniture and construction courses should be included in Industrial training Institutes (ITI) just like carpentry, to create skilled manpower.
4. Ware-housing	53. Absence of proper grading and storage facilities hampers the procurement of bamboo by industries, often leading to damage and poor quality of harvested stock. Bamboo takes greater time and effort as compared to timber for production and construction components, which makes the products relatively expensive to the consumer. Proper warehousing and storage must, therefore, be essential part of the entire processing and production process. Such facilities, must therefore, be developed at strategic locations. [Para: 7.9.5] 54. Large warehouses of manufacturers should be located closer to consumption centres (domestic market and sea ports) for speedy supply of products in domestic and overseas markets at lower cost [Para: 8.12.5] 55. Online marketing of bamboo products should be promoted as it reduces the warehousing needs [Para: 8.12.5]
D. Backward and Forward Linkages	
1. Tax relief	56. Incentives and subsidies should be given by the Government for specific applications of bamboo products with clear environmental advantages [Para: 7.9.6, 8.12.6, 12.6.4] 57. Raw bamboo, primary processed bamboo products and handicraft items ought to be exempted from GST. The rate of GST must be reduced on other products to promote bamboo sector on the lines of khadi, handloom and village industries [Para: 7. 9.7, 8.12.6, 12.6.4] 58. Awareness may be generated about tax relaxations applicable to bamboo sector in order to attract more entrepreneurs and investment [Para: 7.9.7, 8.12.6]
2. Exim policies	59. Import duty on bamboo products must be increased especially for products that have potential of generating mass employment [Para: 7.9.8, 8.12.7] 60. Anti-dumping duty ought to be imposed on cheaper imports of bamboo and bamboo products [Para: 7.9.8, 8.12.7].

Issue	Recommendations
D. Backward and Forward Linkages	
3. Robust market mechanisms	61. Bamboo cooperatives must be formed to help people collectively take up raw material procurement processing, value addition, manufacturing and marketing [Para: 6.7, 7.9.9, 8.12.8] 62. Business development help desk ought to be created at district or block level for providing information to producers, for business counselling, market information, technology information and preparation of business plan [Para: 6.7, 7.9.9, 8.12.8] 63. Digitized information on bamboo resources, producers, consumers, technology, market information etc., ought to be placed online [Para: 6.7, 7.9.5]
4. Infra-structure	64. Uninterrupted supply of water, electricity and chemicals for bamboo industry must be ensured in industrial centres [Para: 7.9.5, 8.12.9]. 65. Suitable transport and communication services must be provided in bamboo value chain [Para: 7.9.5, 8.12.9]
5. Stakeholder linkages	66. A network of bamboo stakeholders may be created to allow exchange of information among all connected with the bamboo sector [Para: 6.7, 4.12.3, 7.9.5, 8.12.10]. 67. A special monthly bulletin or magazine (Bamboo Bulletin) ought to be published in Hindi and English languages to allow exchange of information among all connected with the bamboo sector [Para: 6.7, 4.12.3, 7.9.5, 8.12.10]
E. Research and Development	
1. Productivity enhancement	68. Research institutions must be supported to improve bamboo productivity through silvicultural and genetic approaches within and outside forest areas.[Para: 4.10.1, 7.9.4]
2. Appropriate technologies	69. Organizations, such as ICFRE, IPIRTI and major engineering institutions, must undertake research to develop appropriate and innovative technologies for use of bamboo for traditional as well as modern products. The Govt should provide adequate infrastructural, manpower and financial support to such agencies. [Para: 7.9.4, 8.12.11] 70. Research and development must be undertaken in the area of innovative product designs at the organizations such as the National Institute of Design to help domestic product compete with imported bamboo products and come up with newer products for niche markets. The NIDs must collaborate with other R&D organizations such as ICFRE & IPIRTI for competitive and high quality product development. [Para: 7.9.4, 8.12.11] 71. Suitable species/ clones/ varieties ought to be identified for focused research and development tailored to specific products. [Para: 6.7] 72. The possibility of bamboo flowering prediction model should be explored and preparation of large scale propagation plans should be developed with long-term view [Para 4.10.3] 73. Indian Institutes of Technology (IITs), in collaboration with other organizations, may be entrusted the task of conducting research and development for suitable machines for specific species and products. [Para: 7.9.4, 8.12.11]

Issue	Recommendations
E. Research and Development	
	74. Development of improved tools, techniques, equipment and machinery for bamboo harvesting, processing and product manufacture must be encouraged in the engineering and technology institutions [Para: 7.9.4, 8.12.11] 75. Pilot projects should be launched in different regions of India integrating bamboo producers, primary and secondary processing units, skill development centres, research and technology institutions, markets and all other players in the value chain [Para 12.6.6] 76. A strong mechanism must be developed for database development, including MIS, and continuous up-gradation of the information [Para 2.8]
F. Capacity and Skill Development	
1. Trained manpower	77. Skill development programmes on product-specific as well as species-specific bamboo processing and manufacture must be conducted for artisans and industries [Para: 7.9.10, 8.12.12] 78. Trainers training programmes should also be conducted [Para: 7.9.10, 8.12.12] 79. Training programme for unemployed youth must be conducted under Pradhan Mantri Kaushal Vikas Yojana in leading forestry institutions [Paras: 6.7, 7.9.10, 8.12.12]. Industrial training Institutes (ITI) should take necessary action to popularize bamboo furniture and construction courses to create skilled manpower. 80. Training courses ought to be conducted in Industrial Training Institutes (I.T.I.s) on the use of bamboo for making different products [Para: 7.9.10, 8.12.12] 81. Private plantation owners must be sensitised and trained on sustainable harvest of culms [Para: 6.7, 4.6] 82. People in and around bamboo forests and other growers ought to be trained in management of bamboo forests and plantations [Para: 4.10.3]. 83. Institutions like FRI (Deemed) University, and its centres across the country, can initiate Certificate and Diploma Courses in various aspects of bamboo technology, with support from UGC and Ministry of Human Resource Development. The strong research support of ICFRE and other related organizations such as IPIRTI and CIBART would help to create a strong professional workforce. [Para: 13.2]
G. Legal and Policy Regimes	
1. Supporting livelihood	84. Bamboo is a resource that is capable of socio-economic transformation, besides improving the quality of forests. Bamboo, therefore, needs to be declared as a priority sector [Para 12.1]. 85. People of traditional bamboo-dependent communities, forest-dwellers and other weaker sections of society ought to be employed in bamboo industry on a priority basis, other things being equal, to ensure social justice [Para: 12.4.2] 86. Minimum support price ought to be fixed by the Government for sale of bamboo [Para: 6.7, 12.6.4]

Issue	Recommendations
G. Legal and Policy Regime	
2. Supporting research and development	87. The existing research, technology and training institutions ought to be strengthened for focussed research, technology and extension support to the bamboo sector [Para 12.5, 13.2] 88. A strong mechanism must be developed for database development and continual upgradation [Para 2.8].
3. Harvest and transit rules	89. Felling and transport of bamboo must be brought totally out of Government control in areas where the bamboos are predominantly planted [Para:]. Forestry being on the concurrent list, various states have their own rules in place. Often neighbouring states have different sets of rules, resulting in problems in transit. The harvest and transit rules should be harmonised across the country for ease of business. [Para: 6.7, 12.6.2] 90. In bamboo native areas felling and transit should be exempted from restrictions for bona fide personal use and for artisans in localities where forest is under ownership of forest-dwelling communities under the Joint Forest Management or Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 [Para: 12.6.2] 91. Felling and transit should be controlled by the community-based organizations where forests are owned by individuals, clans or communities especially in the Northeast India, and by the JFMCs in areas allotted under the ST and Other Forest Dwellers (Recognition of Forest Rights) Act, 2006 [Para:12.3.1] 92. SFDs ought to develop standards with local communities to ensure sustainable harvest of bamboo in community-owned areas [Para: 4.4]
4. Governance and institutional reforms	93. Scientific guidelines ought to be issued to SFDs to harvest bamboo at silvicultural rotation, so as to realise greater production; amendments ought to be made in working plans for this purpose, if needed [Para: 4.4] 94. The country should be divided into five regions to frame decentralized policies for each region, owing to variation in the species and the usage. The regions may be north-western region, Ganga basin, central region, north-eastern region and southern region (including Andaman and Nicobar Islands) [Para: 12.3.2] 95. SFDs should help forest-dwellers in better management of bamboo by acting as facilitators to them [Para: 4.7.5] 96. SFDs ought take help of van panchayats, joint forest management committees, self-help groups, bamboo growers' cooperative societies, etc. for managing bamboo in an organised way [Para:]. Felling should be done by above agencies in preference to contractors [4.9.5] 97. The local bodies should be entrusted the responsibility of maintaining bamboo plantations in return for share in the yield [Para: 4.7.5] 98. Tri-partite arrangements may be encouraged among the industry, farmer and a research organization to ensure the quality of planting stock and appropriate silvicultural and management practices, on the lines of pulpwood plantations in South India A quadripartite arrangement may be done adding a bank to the group, if financing is also required [Para: 6.7]

Issue	Recommendations
G. Legal and Policy Regime	
5. National Bamboo Policy	99. A National Bamboo Policy should be formulated as the first step towards developing the bamboo sector. Such a policy would serve to outline the fundamental principles that would guide the State interventions in the bamboo sector, particularly in terms of balancing industry needs with ecological concerns[Para: 12.3.1] 100. Apart from the National Bamboo Policy for the country as a whole, it is recommended that Regional Bamboo Policies should be developed, emanating from the National policy, for five sub-regions in order to account for variations in native species, scale of harvesting, and usage patterns. These five sub-regions would be as North-West, Ganga Basin, Central, North-East and South [Para: 12.3.2]
6. Bamboo Development boards (single vs. multiple owners)	101. The National and Regional Bamboo Policies be implemented through a three-tier structure with a National Bamboo Board and State Bamboo Boards for every state or a group of states and District Bamboo Boards for ever district or group of districts [Para: 12.4] 102. The National Bamboo Development Board may function under the direct administrative control of the Ministry of Environment, Forest and Climate Change, and would have a largely supervisory role. The Bamboo Development Board will have the responsibility of holistic development of bamboo sector [Para: 12.4.1] 103. State Bamboo Development Boards would be responsible for making targeted policy interventions that would support and expand the production of bamboo and bamboo-based products as well as the market for the same. The State Bamboo Boards would work through District Bamboo Boards [Para 12.4.2]
7. Additional role of the forest department	104. The Forest Department is an important stakeholder in the bamboo industry, particularly in the context of harvesting and as such will be represented in the Bamboo Boards and will also provide support to the Boards in discharging their functions. In particular, the Department can provide technical and scientific support [Para 12.5]
H. Mobilisation of Capital and Industry	
1. initiation and promotion of industrial build-up	105. The industry has to play the most crucial role in the development of bamboo sector. Industrialists must be invited and encouraged to invest capital, import/manufacture tools and machinery, set up industrial clusters as well as individual units, and participate at all suitable levels in the value chain [Para 12.6.6] 106. Land, raw material, infrastructure, credit, subsidy, policy regime and all other requirements of the industry should be addressed through a speedy and transparent system [Para 12.6.6] 107. The bamboo industry should be accorded tax concessions and other incentives similar to the khadi industry [Para 12.6.6]

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ANNEXURES

Annexure-I

Promising Genotypes of Important Bamboos Available with ICFRE for Mass Multiplication

Under the National Bamboo Mission (2014-2016) sponsored networking project across the country involving five ICFRE institutes i.e. FRI, TFRI, IWST, IFP, and RFRI, promising gemplasm of priority species, *viz., D. strictus, B. bambos, B. vulgaris, B. tulda, B. nutans, B. balcooa, D. hamiltonii, D. stocksii, D. brandisii and D. somdevai.*, were identified (pl. refer chapter-3). Following tables list the species and available germplasm across the institutes:

Table 1: Selected bamboo clumps by different ICFRE institutes

Species	FRI	TFRI	RFRI	IWST	IFP	Total
Dendrocalamus strictus	24	34	-	22	9	89
Bambusa bambos	-	27	-	13	-	40
B. vulgaris	-	23	-	-	-	23
B. tulda	-	15	07	-	09	31
B. nutans	-	-	03	-	10	13
B. balcooa	-	-	04	-	14	18
D. hamiltonii	-	-	02	-	-	2
Pseudoxytenanthera stocksii	-	-	-	66	-	66
D. somdevai	7	-	-	-	-	7
Total	31	99	16	101	42	289

Annexure-II

Table 2: List of promising clumps of *Dendrocalamus strictus* along with the passport data available at ICFRE institutes

A: *Dendrocalamus strictus* availability at FRI, Dehradun

S. No.	Clump code	Latitude (°N)	Longitude (°E)	Altitude (m)	Height (m)	Inter-node length (cm)	Inter-node diameter (5th int.) (cm)	Wall thickness (5th node) (mm)
1	70(4-16)	28.25°	77.06°	212	15.00	19.93	3.62	18.09
2.	66(4-4)	13.02°	77.57°	920	14.00	24.17	4.13	20.64
3.	177(7-37)	22.49°	72.66°	24	12.50	19.83	3.27	16.34
4.	45(10-12)	29.98°	76.99°	247	13.50	23.17	5.65	28.23
5.	75(10-4)	17.51°	78.44°	494	12.00	26.97	3.03	15.13
6.	36(11-10)	31.53°	75.92°	296	15.00	12.83	1.88	9.39
7.	126(11-23)	27.17°	77.91°	171	15.00	25.83	4.41	22.03
8.	36(11-9)	31.53°	75.92°	296	14.00	19.33	3.55	17.74
9.	36(12-9)	31.53°	75.92°	296	15.00	21.67	4.61	20.56
10.	114(13-20)	30.56°	77.30°	932	14.00	26.00	6.13	30.66
11.	175(13-37)	22.49°	72.66°	24	20.00	25.33	2.99	14.96
12.	175(13-38)	22.49°	72.66°	24	15.00	22.67	4.29	21.46
13.	137(14-25)	30.90°	77.10°	1502	18.00	25.00	3.36	16.78
14.	109(15-17)	30.51°	77.84°	780	17.00	21.87	2.48	12.41
15.	109(15-18)	30.51°	77.84°	780	15.00	21.67	4.71	23.55
16.	175(15-38)	22.49°	72.66°	24	22.00	24.97	3.14	15.70
17.	48(17-11)	29.98°	76.99°	247	18.00	27.50	4.29	21.44
18.	171(17-35)	25.13°	82.56°	80	20.00	25.17	2.75	13.75
19.	171(18-36)	25.13°	82.56°	80	15.50	20.33	3.71	16.03
20.	71(6-16)	30.79°	76.92°	365	13.80	22.67	2.70	13.51
21.	45(10-11)	29.98°	76.99°	247	14.00	25.67	3.38	14.75
22.	168(10-36)	25.13°	82.56°	80	14.00	20.87	4.23	20.15
23.	177(10-38)	22.49°	72.66°	24	18.00	19.17	3.24	14.68
24.	170(16-36)	25.13°	82.56°	80	19.00	18.33	2.68	10.91

B: *Dendrocalamus strictus* availability at IWST, Bengaluru

S. No.	Clump code	Latitude (°N)	Longitude (°E)	Altitude (m)	Height (m)	Inter-node length (cm)	Inter-node diameter (5th int.) (cm)	Wall thickness (5th node) (mm)
1.	1	15.29'	74°52'37.6"	674	7.00	23.70	3.93	1.45
2.	3	14°36'38.7"	74°52'37.6"	609	8.50	19.80	3.80	1.50
3.	4	14°36'38.97	74°52'37.6"	609	8.50	19.80	3.66	1.28
4.	6	14°36'37.8"	74°52'37.6"	609	10.50	24.50	3.96	1.47
5.	10	14°36'38.7"	74°52'37.6"	609	9.00	23.30	3.60	1.51
6.	16	14°36'38.7"	74°52'37.6"	609	6.50	21.30	3.66	1.22
7.	19	14°36'38.7"	74°52'37.6"	609	8.80	24.40	3.53	1.32
8.	25	14°36'38.7"	74°52'37.6"	609	9.70	22.80	3.03	1.09
9.	27	14°36'38.7"	74°52'37.6"	609	7.50	25.00	3.40	1.55
10.	36	14°37'42.7"	74°52'37.6"	618	8.00	23.00	3.33	1.36
11.	40	14°37'42.7"	74°52'37.6"	618	8.50	24.80	3.26	1.40
12.	93	15°18'46.3"	74°36'19.3"	572	17.00	22.80	6.68	1.70
13.	94	15°18'16.3"	74°36'19.3"	572	16.00	25.50	4.58	1.46
14.	98	15°18'46.3"	74°36'19.3"	572	18.00	24.10	6.06	1.96
15.	101	15°18'46.3"	74°36'19.3"	572	18.00	23.10	5.20	1.60
16.	103	15°20'50.0"	74°46'55.9"	559	12.00	25.30	4.50	1.70
17.	110	15°20'50.0"	74°46'55.9"	595	12.00	22.50	5.78	1.80
18.	113	15°20'50.0"	74°46'55.9"	595	15.00	25.60	4.23	1.60
19.	118	15°20'50.0"	74°46'55.9"	595	18.00	31.00	6.69	1.70
20.	126	15°20'53.9"	74°46'19.5"	584	23.00	24.80	6.14	1.80
21.	139	15°18'57.4"	74°45'16.1"	595	13.00	30.10	6.20	1.70
22.	150	13°25'28.5"	74°29'1.0"	954	20.00	21.30	4.00	1.40

C: *Dendrocalamus strictus* availability at TFRI, Jabalpur

S. No.	Clump code	Latitude (°N)	Longitude (°E)	Altitude (m)	Height (m)	Inter-node length (cm)	Inter-node diameter (5th int.) (cm)	Wall thickness (5th node) (mm)
1.	OR-AG-1	21°01'38.4"	84°55'14.6"	201	20.00	15.80	2.07	18.00
2.	MP-SE-1	22°02'06.1"	79°47'37.9"	560	7.80	19.00	5.73	14.00
3.	MP-SE-2	22°02'06.1"	79°47'37.9"	561	7.60	16.00	4.45	12.00
4.	MP-SE-3	22°02'06.1"	79°47'37.9"	560	7.50	19.00	4.77	13.00
5.	MP-SE-4	22°02'06.1"	79°47'37.9"	560	6.80	15.00	4.45	15.00
6.	MP-SE-5	2o°2'06.1"	79°47'37.9"	560	6.90	18.00	4.45	14.00
7.	TFRI-2	23°05'58.2"	79°59'21.7"	409	8.51	99.00	5.73	15.00
8.	TFRI-3	23°05'58.5"	79°59'21.6"	413	9.63	112.00	5.09	15.00
9.	TFRI-4	23°05'59.9"	79°59'22.1"	413	8.34	97.00	4.77	15.00
10.	MP-CHH-4	21°45'44.6"	78°49'48.2"	367	7.30	19.00	5.41	15.00
11.	MP-CHH-5	21°45'42.7"	78°49'49.0"	368	7.50	20.00	5.09	15.00
12.	MP-MAN-1	22°38'22.9"	80°21'33.3"	461	9.50	27.00	3.82	15.00
13.	MP-MAN-2	22°38'22.9"	80°21'33.3"	461	8.00	22.00	3.50	15.00
14.	MP-MAN-3	22°38'22.9"	80°21'33.3"	461	8.00	21.00	3.34	15.00
15.	MP-MAN-4	22°38'22.9"	80°21'33.3"	461	8.50	21.50	3.34	15.00
16.	MP-BA-3	22°07'46.2"	80°07'49.3"	288	10.80	19.00	4.77	5.00
17.	MP-BA-4	22°07'46.2"	80°07'49.3"	287	13.60	22.00	5.41	7.00
18.	MP-BA-5	22°07'46.2"	80°07'49.3"	286	14.20	23.00	5.73	6.00
19.	CG-TA-3	22°10'57.8"	83°27'23.8"	214	9.00	24.00	4.14	15.00
20.	CG-TA-4	22°10'57.8"	83°27'23.8"	215	9.00	26.00	4.30	20.00
21.	CG-TA-5	22°10'57.8"	83°27'23.8"	216	8.50	21.00	3.90	15.00
22.	CG-TA-3-New	22°10'43.8"	83°27'29.7"	218	8.00	19.00	2.54	15.00
23.	CG-TA-4-New	22°1°'43.8"	83°27'29.7"	218	7.00	20.00	2.23	10.00
24.	CG-TA-5-New	22°10'43.8"	83°27'29.7"	219	7.60	19.00	2.54	15.00
25.	CG-RAIPUR-4	21°14'13.4"	81°49'44.5"	299	9.50	13.00	2.07	20.00
26.	CG-RAIPUR-5	21°14'13.4"	81°49'44.5"	297	8.00	8.50	1.91	15.00
27.	BAN-RGH-4	21°59'54.8"	83°28'58.0"	223	9.80	27.00	5.09	25.00
28.	BAN-RGH-5	21°59'54.8"	83°28'58.0"	221	9.10	26.50	4.61	20.00

29.	JAM-RGH-5	22°02'29.8''	83°12'19.7''	216	17.50	22.00	4.14	20.00
30.	OR-GH-1	20°16'35.7'	85°46'50.8''	61	13.00	16.70	4.90	25.00
31.	MP-RAN-1	2.3°06'60.2''.	79°57'20.6''	424	16.50	16.00	4.14	22.00
32.	MP-RAN-2	23°06'62.4''	79°58'21.4''	423	14.50	14.00	3.82	21.00
33.	MP-RAN-3	23°06'65.2''	79°57'21.7''	425	13.00	12.00	3.50	19.00
34.	MP-RAN-4	23°06'640.3''	79°57'28.6''	424	16.00	18.00	4.45	23.00

D: *Dendrocalamus strictus* availability at IFP, Ranchi

S. No.	Clump code	Latitude (°N)	Longitude (°E)	Altitude (m)	Height (m)	Inter-node length (cm)	Inter-node diameter (5th int.) (cm)	Wall thickness (5th node) (mm)
1.	IFP/DS/1	23°40'36.5"	84°43'36.9"	534	23.00	27.00	6.00	-
2.	IFP/DS/2	23°40'31.0"	84°43'43.8"	533	22.00	21.00	9.00	-
3.	IFP/DS/3	23°40'33.1"	84°43'36.3"	535	23.00	23.00	6.00	-
4.	IFP/DS/4	22°29'52.6"	86°37'15.8"	122	12.00	22.00	4.00	-
5.	IFP/DS/5	23°01'55.5"	84°34'24.8"	669	12.00	23.00	5.00	-
6.	IFP/DS/6	23°21'22.9"	85°14'39.6"	725	20.00	25.00	5.50	-
7.	IFP/DS/7	23°17'26.0"	84°59'8.1"	769	16.00	27.00	4.00	-
8.	IFP/DS/8	23°14'9.1"	84°53'55.2"	677	24.00	26.00	4.50	-
9.	IFP/DS/9	26°45'30.7"	88°23'49.2"	135	13.00	34.00	2.05	-

Annexure-III

Table 3: List of promising clumps of *D. somdevai* along with the passport data available at FRI

S. No.	Clump code	Geographical coordinates			Growth characteristics of clumps			
		Latitude (°N)	Longitude (°E)	Altitude (m)	Height (m)	Inter-node length (cm)	Inter-node diameter (5th int.) (cm)	Wall thickness (5th node) (mm)
1.	HDS1	31.50°	76.65°	301	17.00	32.00	8.05	25.00
2.	HDS2	31.53°	76.62°	830	18.00	28.00	8.90	28.00
3.	HDS3	31.55°	76.61°	800	18.00	39.00	9.10	32.00
4.	HDS4	31.62°	76.56°	753	18.00	38.00	9.30	31.00
5.	HDS5	31.64°	76.55°	754	18.00	27.00	8.40	27.00
6.	HDS6	31.72°	76.51°	800	14.00	18.00	8.41	28.00
7.	HDS7	31.73°	76.50°	827	18.00	32.00	9.90	34.00

Annexure-IV

Table 4: List of promising clumps of Bambusa bambos along with the passport data available at ICFRE Institutes

A: *Bambusa bambos* availability at IWST, Bengaluru

S. No.	Clump code	Geographical coordinates			Growth characteristics of clumps			
		Latitude (°N)	Longitude (°E)	Altitude (m)	Height (m)	Inter-node length (cm)	Inter-node diameter (5th int.) (cm)	Wall thickness (5th node) (mm)
1.	1	15°28'28.9"	74°59'9.6"	674	27.00	27.30	10.00	2.33
2.	2	15°9'20.9"	74°42'1.8"	473	28.00	24.10	8.60	2.10
3.	3	15°7'59.3"	74°32'1.6"	474	34.00	22.10	12.00	2.96
4.	4	15°7'59.1"	74°32'1.8"	474	35.00	21.60	13.00	2.30
5.	5	15°5'34.4"	74°30'59.2"	474	36.00	17.00	13.00	2.00
6.	6	15°3'41.4"	74°31'12.4"	558	39.00	22.40	11.00	2.13
7.	7	15°10'2.3"	74°38'22.9"	504	33.00	22.10	9.00	2.10
8.	8	14°45'25.2"	74°49'45.9"	513	22.00	27.10	11.00	2.42
9.	9	14°52'10.2"	74°51'24.7"	501	21.00	19.80	9.00	3.50
10.	10	15°5'19.5"	74°44'47.6"	520	24.00	26.00	10.00	3.65
11.	11	14°57'54.6"	74°41'56.8"	558	21.00	24.00	10.00	3.25
12.	12	15°57'54.6"	74°41'56.8"	558	24.00	30.00	11.00	3.25
13.	13	14°36'38.7"	74°52'37.6"	609	20.00	24.50	8.00	3.00

B: *Bambusa bambos* availability at TFRI, Jabalpur

1.	MP-KATRA-1	22°38'21.3''	80°21'34.0''	451	12.50	11.00	6.68	15.00
2.	MP-KATRA-2	22°38'21.3''	80°21'34.0''	451	13.00	11.50	7.48	10.00
3.	CG-BSP-5	22°11'49.2''	82°07'42.2''	264	14.00	13.50	7.00	22.00
4.	MP-TF-1	23°05'57.2''	79°59'22.3''	411	17.23	88.00	9.61	30.00
5.	MP-TF-3	23°05'59.5''	79°59'22.6''	409	16.80	74.00	10.44	31.00
6.	MP-TF-4	23°05'59.6''	79°59'23.1''	413	17.30	89.00	10.28	31.00
7.	BGNS-FF-1	21°58'31. 9''	83°28'23.2''	220	25.00	19.00	7.32	21.00
8.	CG-RGH-1	21°57'52.2''	83°28'29.4''	296	15.50	15.00	9.07	20.00
9.	CG-RGH-2	21°57'52.2''	83°28'29.4''	295	16.00	17.50	9.23	21.00
10.	CG-RGH-3	21°57'52.2''	83°28'29.4''	293	16.00	14.00	9.39	19.00
11.	CG-RGH-4	21°57'52.2''	83°28'29.4''	295	17.50	16.50	10.35	19.00
12.	CG-RGH-5	21°57'52.2''	83°28'29.4''	292	18.00	19.50	10.82	25.00
13.	MP-CHH-5	21°45'35.0''	78°49'49.5''	352	23.00	36.00	10.19	21.00

14.	MP-SE-BA-1	21°01'52.1''	84°55'13.3''	590	23.00	35.00	9.55	28.00
15.	MP-SE-BA-2	21°01'52.1''	84°55'13.3''	590	24.00	34.00	9.87	28.00
16.	MP-SE-BA-3	21°01'52.1''	84°55'13.3''	590	23.00	36.00	10.50	40.00
17.	MP-SE-BA-4	21°01'52.1''	84°55'13.3''	590	24.00	35.00	10.19	30.00
18.	MP-SE-BA-5	21°01'52.1''	84°55'13.3''	590	23.00	36.00	10.19	22.00
19.	CG-JDGP-1	19°11'11.4''	82°03'43.9''	552	12.00	27.00	6.24	21.00
20.	CG-JDGP-3	19°11'11.4''	82°03'43.9''	555	9.80	26.10	5.85	20.00
21.	CG-JDGP-5	19°11'11.4''	82°03'43.9''	551	10.80	26.70	6.08	21.00
22.	LA-NAG-1	22°10'43.9''	83°27'29.8''	309	14.50	20.10	8.91	8.00
23.	LA-NAG-2	22°10'43.9''	83°27'29.8''	308	13.00	20.30	8.28	9.00
24.	LA-NAG-3	22°10'43.9''	83°27'29.8''	310	16.80	19.00	10.19	8.00
25.	LA-NAG-4	22°10'43.9''	83°27'29.8''	309	15.20	20.00	8.91	9.00
26.	LA-NAG-5	22°10'43.9''	83°27'29.8''	309	13.40	22.00	9.55	9.00
27.	MP-RANG-4	23°06'61.3''	79°57'22.6''	424	17.00	23.00	5.41	29.00

Annexure-V

Table 5: List of promising clumps of *Pseudoxytenanthera stocksii* along with passport data, available at IWST, Bengaluru

A: *Pseudoxytenanthera stocksii* availability at IWST, Bengaluru

S. No.	Clump code	Geographical coordinates			Growth characteristics of clumps			
		Latitude (°N)	Longitude (°E)	Altitude (m)	Height (m)	Inter-node length (cm)	Inter-node diameter (5th int.) (cm)	Wall thickness (5th node) (mm)
1.	2	17°55'02.70"	73°16'51.98"	176.20	14.90	35.20	4.74	10.46
2.	5	15°43'43.85"	74°01'34.52"	67.97	13.00	41.00	4.08	8.33
3.	6	16°16'27.60"	74°21'50.51"	656.54	12.30	44.80	4.01	7.80
4.	7	15°41'16.38"	74°31'11.09"	749.80	12.70	32.86	3.85	12.33
5.	10	17°44'43.38"	73°11'08.34"	182.73	7.10	34.96	4.05	7.58
6.	14	15°47'17.30"	74°02'22.90"	138.68	11.40	39.00	3.32	9.20
7.	16	15°50'20.52"	73°54'42.19"	239.88	12.30	36.40	4.02	8.53
8.	22	15°56'06.52"	73°53'27.79"	68.88	8.50	34.00	2.99	10.28
9.	23	16°00'25.00"	73°43'09.84"	33.83	8.20	30.40	3.40	8.17
10.	24	16°01'34.78"	73°52'18.20"	154.83	5.40	33.00	3.61	18.02
11.	27	14°35'27.80"	74°52'48.05"	572.20	8.50	25.20	4.23	10.71
12.	31	14°29'34.80"	75°51'53.10"	632.30	9.35	30.52	4.27	9.68
13.	34	15°25'16.70"	74°50'20.50"	657.76	9.90	32.58	3.40	7.64
14.	35	14°41'10.90"	74°49'41.40"	541.49	13.70	41.60	3.46	10.81
15.	36	14°58'51.60"	74°27'21.50"	471.83	15.50	32.00	1.25	11.72
16.	37	14°39'23.70"	74°50'91.10"	469.69	15.90	41.80	4.82	10.32
17.	38	14°41'10.90"	74°49'41.40"	537.67	12.50	44.00	4.43	14.16
18.	39	14°29'12.50"	74°59'09.20"	567.84	10.60	32.94	4.17	4.72
19.	40	15°06'39.50"	74°23'31.80"	617.82	8.30	25.30	2.61	11.23
20.	43	12°11'50.80"	75°09'53.20"	10.70	8.30	30.00	3.68	18.42
21.	45	12°17'49.10"	75°06'10.50"	82.00	14.60	31.98	4.06	15.39
22.	47	12°29'57.00"	75°00'26.20"	190.00	10.20	33.00	3.90	6.73
23.	48	12°30'15.04"	75°02'50.60"	275.80	10.00	29.96	3.57	10.12
24.	49	12°29'55.50"	75°05'00.80"	94.40	9.20	35.40	3.84	19.19
25.	51	12°33'50.20"	75°03'54.60"	123.75	8.10	26.80	3.45	9.69
26.	52	15°40'37.50"	74°00'18.90"	60.96	9.00	34.78	3.94	8.31

27.	53	15°38'18.50"	74°02'39.20"	299.92	10.20	26.90	3.99	7.48
28.	54	15°42'25.60"	73°51'10.30"	110.40	11.50	30.00	3.51	7.58
29.	55	15°42'18.00"	73°44'51.70"	33.60	11.00	31.98	4.47	11.53
30.	56	15°43'23.20"	73°47'26.90"	106.90	13.00	35.18	3.67	6.57
31.	57	16°04'23.70"	74°05'38.90"	674.00	12.30	36.40	3.46	5.79
32.	58	16°07'22.50"	74°10'19.20"	748.50	11.70	32.00	3.52	9.00
33.	59	16°08'35.80"	74°17'21.30"	660.00	8.10	36.40	3.41	10.66
34.	60	16°07'47.10"	74°22'23.00"	825.70	11.80	32.62	3.80	7.80
35.	63	15°53'00.90"	74°17'23.70"	809.10	9.20	32.77	3.61	8.24
36.	64	15°52'01.40"	74°19'17.50"	721.30	7.50	17.50	2.15	11.99
37.	67	15°32'49.00"	74°34'56.50"	886.10	10.70	32.64	3.76	9.54
38.	68	15°44'37.40"	74°30'40.50"	762.40	13.60	39.20	4.57	10.49
39.	69	15°51'34.10"	74°34'15.50"	759.10	12.00	32.05	4.34	21.70
40.	70	16°46'04.40"	73°44'36.70"	586.90	11.20	30.60	3.48	11.54
41.	71	13°20'58.40"	74°50'51.43"	174.60	9.40	28.22	3.40	7.86
42.	72	13°17'08.90"	74°54'43.00"	71.87	12.50	37.20	3.68	10.90
43.	73	13°12'46.20"	74°58'45.20"	66.50	11.10	31.34	3.62	4.31
44.	76	13°23'46.00"	74°55'03.80"	68.40	7.00	23.30	3.06	14.08
45.	78	15°23'09.90"	74°03'02.00"	144.50	9.20	34.20	3.80	9.28
46.	79	15°15'14.50"	73°58'49.20"	26.29	8.30	29.68	4.11	20.93
47.	80	15°06'26.40"	73°56'27.10"	46.90	9.00	26.06	3.55	14.33
48.	82	15°29'00.50"	74°09'12.60"	112.50	7.80	31.20	3.77	9.89
49.	83	15°25'24.70"	74°11'44.40"	95.50	15.00	35.26	4.03	10.28
50.	87	17°21'15.60"	73°49'50.20"	562.42	10.80	31.86	3.64	8.15
51.	89	17°40'46.00"	73°30'52.20"	71.50	7.90	30.12	3.43	10.75
52.	90	17°08'20.80"	73°33'48.90"	105.20	8.10	31.67	2.76	9.57
53.	91	17°06'04.80"	73°34'28.70"	118.10	12.50	41.40	3.98	25.00
54.	92	16°59'16.10"	73°42'05.10"	164.40	14.00	36.30	3.82	7.29
55.	93	16°59'53.70"	73°46'10.50"	407.80	11.90	36.60	4.39	7.98
56.	94	16°54'25.70"	73°31'12.90"	164.85	13.70	39.80	3.81	8.92
57.	95	16°46'18.30"	73°24'55.40"	106.80	7.90	30.92	2.98	7.45
58	97	17°42'02.80"	73°12'05.70"	112.40	10.40	28.03	4.21	13.10
59.	99	17°43'46.50"	73°17'22.30"	161.30	11.82	33.02	3.47	11.03
60.	100	17°45'08.30"	73°16'26.70"	192.20	10.80	37.38	3.385	7.87

B: *Pseudoxytenanthera stocksii* availability at UAS, Dharwad

1	14	14°41'10.9"	74°49'41.4"	535.00	11.50	35.30	3.50	1.50
2	15	14°41'10.9"	74°49'41.4"	535.00	12.50	38.60	3.80	1.90
3	17	14°39'23.7"	74°50'19.1"	624.00	12.50	40.30	4.20	1.93
4	18	14°41'10.9"	74°49'41.4"	535.00	9.50	40.60	3.80	1.66
5	23	14°41'43"	74°49'41.4"	531.00	10.00	35.60	3.30	1.58
6	24	14°41'10.9"	74°49'25.6"	531.00	10.00	41.30	3.30	1.43

Annexure-VI

Table 6: List of promising clumps of *Bambusa tulda* along with the passport data, available at different ICFRE institutes

A: *Bambusa tulda* availability at TERI, Jabalpur

S. No.	Clump code	Geographical coordinates			Growth characteristics of clumps			
		Latitude (°N)	Longitude (°E)	Altitude (m)	Height (m)	Inter-node length (cm)	Inter-node diameter (5th int.) (cm)	Wall thickness (5th node) (mm)
1.	OR-KO-3	21°61'39.9''	84°55'11.6''	269.00	12.00	30.00	4.90	20.00
2.	OR-KO-4	21°61'39.9''	84°55'11.6''	269.00	15.00	15.80	3.63	15.00
3.	OR-GHA-1	20°16'42.6''	85°46'55.6''	75.00	16.00	25.40	6.21	23.00
4.	OR-GHA-3	20°16'42.6''	85°46'55.6''	75.00	13.00	18.80	6.72	17.00
5.	OR-GHA-4	20°16'42.6''	85°46'55.6''	75.00	19.00	23.10	5.89	22.00
6.	MP-TF-1	23°05'57.2''	79°59'23.3''	408.00	9.10	149.00	5.41	20.00
7.	MP-TF-2	23°05'56.2''	79°59'20.7''	409.00	8.60	142.00	5.41	20.00
8.	MP-TF-3	23°05'56.5''	79°59'22.6''	411.00	8.10	140.00	5.73	21.00
9.	MP-TF-4	23°05'56.9''	79°59'22.1''	410.00	8.60	144.00	6.05	21.00
10.	CG-BSP-2	22°04'49.0''	82°03'58.3''	328.00	19.00	18.00	7.16	18.00
11.	CG-BSP-3	22°04'49.0''	82°03'58.3''	328.00	21.50	17.00	7.64	15.00
12.	CG-BSP-4	22°04'49.0''	82°03'58.3''	328.00	20.00	18.00	6.84	20.00
13.	MP-TF-NW-1	23°06'05.2''	79°59'24.9''	410.00	7.50	40.00	5.09	20.00
14.	MP-TF-NW-4	23°06'09.6''	79°59'22.1''	406.00	8.50	41.50	5.25	22.00
15.	MP-TF-NW-5	23°06'08.3''	79°59'24.6''	406.00	8.00	42.00	5.25	20.00

B. *Bambusa tulda* availability at RFRI, Jorhat

1.	RFRI/Bt-01	26.44°	91.44°	42.00	16.70	48.24	61.13	13.50
2.	RFRI/Bt-07	26.32°	91.00°	43.00	16.30	21.21	78.97	12.50
3.	RFRI/Bt-18	26.98°	94.63°	95.00	16.50	48.08	75.36	13.20
4.	RFRI/Bt-34	26.75°	94.22°	116.00	15.00	45.08	67.15	13.20
5.	RFRI/Bt-98	26.32°	91.00°	43.00	16.00	47.00	72.00	13.60
6.	RFRI/G/Bt-01	26.60°	94.20°	172.00	16.20	49.76	68.54	16.20
7.	RFRI/Bt-A20	Detail N.A.	-	-	16.00	48.30	73.91	13.20

C. *Bambusa tulda* availability at IFP, Ranchi

1.	IFP/BT/1	26°48'36.5"	88°57'48.4"	144.00	12.00	35.00	6.50	-
2.	IFP/BT/2	23°21'43.3"	86°32'33.9"	262.00	12.00	41.00	5.50	-
3.	IFP/BT/3	23°21'21"	85°14'39.8"	705.00	18.00	57.00	5.00	-
4.	IFP/BT/4	23°21'21.2"	85°14'39.8"	731.00	18.00	57.00	5.00	-
5.	IFP/BT/5	26°45'14.8"	88°58'02.8"	113.00	13.50	23.00	6.50	-
6.	IFP/BT/6	23°21'21.9"	85°14'38.5"	822.00	23.00	60.00	6.50	-
7.	IFP/BT/7	22°32'49.5"	87°15'41.3"	59.00	10.00	45.00	4.00	-
	IFP/BT/8	23°21'23.9"	85°14'38.8"	723.00	13.00	53.00	5.00	-
	IFP/BT/9	23°21'22.5"	85°14'28.9"	749.00	12.00	45.00	5.00	-

Annexure-VII

Table 7: List of promising clumps of *Bambusa balcooa* along with the passport data, available at different ICFRE institutes

A. *Bambusa balcooa* availability at RFRI, Jorhat

S. No.	Clump code	Geographical coordinates			Growth characteristics of clumps			
		Latitude (°N)	Longitude (°E)	Altitude (m)	Height (m)	Inter-node length (cm)	Inter-node diameter (5th int.) (cm)	Wall thickness (5th node) (mm)
1.	RFRI/BBA-03	26.20°N	91.15°E	55.50	15.00	22.13	5.62	21.00
2.	RFRI/BBA-04	27.24°N	94.11°E	101.00	16.60	21.22	8.13	20.50
3.	RFRI/BBA-14	26.98°N	94.63°E	95.00	17.00	23.33	7.31	21.75
4.	RFRI/BBA-21	26.32°N	91.00°E	43.00	15.60	21.49	6.30	20.00

B. *Bambusa balcooa* availability at IFP, Ranchi

1.	IFP/BB/1	23°40'34.2"	84°43'36.8"	538.00	28.00	30.00	9.00	-
2.	IFP/BB/2	23°40'32.7"	84°43'41.7"	535.00	25.00	31.00	9.00	-
3.	IFP/BB/3	23°40'40.2"	84°43'42.1"	532.00	26.00	33.00	9.00	-
4.	IFP/BB/4	26°45'21.5"	88°58'10.3"	113.00	13.50	23.00	7.00	-
5.	IFP/BB/5	25°58'24.3"	87°18'46.8"	42.00	22.00	41.00	8.00	-
6.	IFP/BB/6	22°29'47.9"	86°37'17.9"	122.00	23.00	33.00	6.50	-
7.	IFP/BB/7	22°29'04.9"	86°42'55.9"	231.00	22.00	40.00	4.00	-
8.	IFP/BB/8	24°00'20.1"	85°21'05.9"	653.00	23.00	23.00	8.00	-
9.	IFP/BB/9	22°35'38"	87°15'53.9"	61.00	25.00	24.00	7.00	-
10.	IFP/BB/10	23°17'27.3"	84°59'10.4"	705.00	22.00	21.00	6.50	-
11.	IFP/BB/11	23°09'45.8"	84°43'43.1"	623.00	20.00	30.00	8.00	-
12.	IFP/BB/12	23°14'09.6"	84°53'55.9"	668.00	30.00	30.00	9.00	-
13.	IFP/BB/13	23°01'55.2"	84°34'28.8"	665.00	25.00	33.00	8.00	-
14.	IFP/BB/14	24°03'24.2"	84°31'37.7"	305.00	18.00	32.00	7.00	-

Annexure-VIII

Table 8: List of promising clumps of *Bambusa nutans* along with the passport data, available at different ICFRE institutes

A. *Bambusa nutans* availability at RFRI Jorhat

S. No.	Clump code	Geographical coordinates			Growth characteristics of clumps			
		Latitude (°N)	Longitude (°E)	Altitude (m)	Height (m)	Inter-node length (cm)	Inter-node diameter (5th int.) (cm)	Wall thickness (5th node) (mm)
1.	RFRI/BN-05	27.24°N	94.11°E	101.00	16.80	33.83	6.70	13.50
2.	RFRI/BN-16	27.24°N	94.11°E	101.00	17.00	33.10	6.82	13.25
3.	RFRI/BN-02(G)	26.98°N	94.63°E	95.00	17.00	32.06	6.40	16.25

B. *Bambusa nutans* availability at IFP, Ranchi

1.	IFP/BN/1	26°45'14.8"	88°58'02.8"	113.00	12.00	40.00	6.80	-
2.	IFP/BN/2	22°37'50.2"	85°21'39.8"	113.00	24.00	35.50	9.00	-
3.	IFP/BN/3	23°21'24.0"	85°14'36.5"	716.00	23.00	32.00	11.00	-
4.	IFP/BN/4	26°45'14.8"	88°58'02.8"	113.00	20.00	33.00	8.00	-
5.	IFP/BN/5	23°21'21.11"	85°14'40.0"	711.00	12.00	40.00	6.80	-
6.	IFP/BN/6	26°45'33.9"	88°23'49.1"	134.00	22.00	33.00	7.00	-
7.	IFP/BN/7	24°03'32.7"	84°08'35.3"	260.00	20.00	23.00	8.50	-
8.	IFP/BN/8	26°45'34.1"	88°23'50.0"	135.00	13.00	22.00	2.50	-
9.	IFP/BN/9	26°45'31.3"	88°23'49.3"	133.00	17.00	45.00	7.00	-
10.	IFP/BN/10	26°45'32.2"	88°23'49.7"	132.00	19.00	46.00	7.00	-

Annexure-IX

Table 9: List of promising clumps of *Bambusa vulgaris* along with the passport data, available at TFRI Jabalpur

A. *Bambusa vulgaris* availability at TFRI, Jabalpur

S. No.	Clump code	Geographical coordinates			Growth characteristics of clumps			
		Latitude (°N)	Longitude (°E)	Altitude (m)	Height (m)	Inter-node length (cm)	Inter-node diameter (5th int.) (cm)	Wall thickness (5th node) (mm)
1.	CG-JGDP-1	19°11'11.1''	82°03'44.9''	552.00	7.90	27.90	5.09	12.00
2.	CG-JGDP-2	19°11'04.4''	82°03'43.9''	551.00	8.60	29.10	5.76	12.00
4.	CG-JGDP-4	19°11'10.6''	82°03'44.9''	554.00	8.30	28.50	5.67	13.00
5.	CG-JGDP-5	19°11'09.4''	82°03'42.8''	555.00	7.40	28.10	5.00	13.00
6.	MP-TFSIL-1	23°05'58.2''	79°59'01.0''	415.00	11.50	30.00	5.73	20.00
7.	MP-TFSIL-2	23°05'59.1''	79°59'00.8''	413.00	17.00	32.00	7.96	25.00
10.	MP-TFSIL-5	23°05'58.4''	79°59'01.0''	411.00	16.50	20.00	4.45	20.00
11.	OR-KO-1	21°01'26.0''	84°55'21.0''	198.00	15.00	24.70	4.45	18.00
12.	OR-KO-2	21°01'26.0''	84°55'21.0''	198.00	18.00	22.00	3.06	21.00
13.	OR-KO-3	21°01'26.0''	84°55'21.0''	198.00	13.00	23.50	4.30	20.00
14.	OR-KO-4	21°01'26.0''	84°55'21.0''	198.00	12.00	22.50	4.77	29.00
15.	OR-GHA-1	20°16'42.4''	85°46'53.6''	102.00	25.00	17.00	8.43	28.00
16.	OR-GHA-2	20°16'42.4''	85°46'53.6''	102.00	20.00	21.00	7.10	22.00
17.	OR-GHA-3	20°16'42.4''	85°46'53.6''	102.00	18.00	18.30	7.51	19.00
18.	OR-GHA-4	20°16'42.4''	85°46'53.6''	102.00	22.00	20.00	8.91	25.00
19.	CG-RAI-1	21°22'59.1''	81°49'37.3''	295.00	9.40	28.60	6.17	20.00
20.	CG-RAI-2	21°22'59.0''	81°49'37.2''	296.00	11.20	29.50	6.68	20.00
21.	CG-RAI-3	21°22'58.9''	81°49'36.3''	293.00	8.90	28.70	5.95	19.00
22.	CG-RAI-4	21°22'59.4''	81°49'34.3''	294.00	10.20	29.40	6.49	21.00
23.	CG-RAI-5	21°22'58.6''	81°49'33.3''	295.00	10.50	29.60	6.49	20.00

Annexure-X

Table 10: List of promising clumps of *Dendrocalamus hamiltonii* along with the passport data, available at RFRI Jorhat

A. *Dendrocalamus hamiltonii* availability at RFRI, Jorhat

S. No.	Clump code	Geographical coordinates			Growth characteristics of clumps			
		Latitude (°N)	Longitude (°E)	Altitude (m)	Height (m)	Inter-node length (cm)	Inter-node diameter (5th int.) (cm)	Wall thickness (5th node) (mm)
1.	RFRI/Dh- 24	25.84°	91.98°	485.00	17.57	37.71	71.49	14.70
2.	RFRI/Dh-50	25.35°	93.02°	513.00	17.23	28.34	68.30	16.00

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