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Proceedings of a workshop held in Singapore 28-30 May 1980

Editors:
Gilles Lessard and Amy Chouinard

Organized by the International Development Research Centre and the International Union of Forestry Research Organizations

# Bamboo Research in Asia

INTERNATIONAL DEVELOPMENT RESEARCH CENTRE • CENTRE DE RECHERCHES POUR LE DÉVELOPPEMENT INTERNATIONAL
CANADA

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*The cover artwork, which has been reproduced throughout the book, is a line drawing based on a painting by Hui Nien, which has been used in several works on bamboo.*

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# Bamboo Research in Asia

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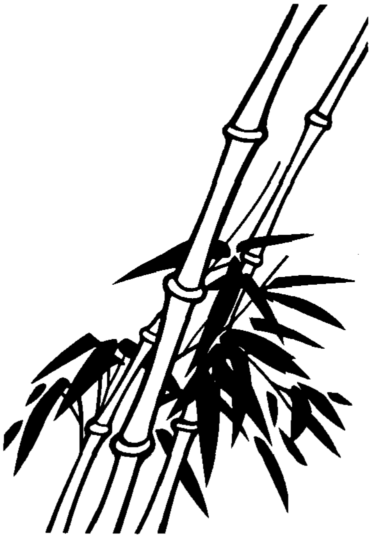
**Editors: Gilles Lessard and Amy Chouinard**

*Organized by the International Development Research Centre and the International Union of Forestry Research Organizations*

# Contents



# Foreword

The bamboos are plants of enormous importance to the rural people in several regions of the world, but nowhere is their usefulness as great as in South and Southeast Asia. Bamboo is used for house construction, scaffolding, ladders, mats, baskets, fencing, containers, tool handles, pipes, toys, musical instruments, cooking pots, furniture, handicrafts, etc., and for several other articles of everyday use, including paper. It is also used for fuel, food, and feed. It is indeed difficult to imagine what the people in Asia would do without bamboo. In the populous countries of China and India, practically every inhabitant is, throughout life, using bamboo in many ways. If other Asian countries where bamboo is abundant are taken into account, it is possible to estimate that at least one-third of the human race is making use of this perennial plant. Considering the importance of bamboo in the lives of so many people, it is remarkable that there has never been in the past an international meeting of research scientists interested in bamboo.

The International Development Research Centre (IDRC) and the International Union of Forestry Research Organizations (IUFRO) share the common objectives of encouraging forest research for the advancement of science and for development. A few years ago, discussions were held between representatives of IDRC and IUFRO to find ways for mutual cooperation, particularly with regard to enhancing tropical forestry research for the benefit of developing countries. Bamboo was considered a good subject, and a decision was made to hold a joint regional workshop on bamboo research in Asia in 1980.

The main objectives of the workshop were:

- To review existing knowledge on the cultivation and utilization of bamboo in Asia;
- To consider the most important problems and constraints preventing the greater use of the bamboo resource in the region; and,
- To identify regional research needs and priorities on bamboo cultivation and utilization.

During the first day of the 3-day workshop, the participants from nine Asian countries presented reports on the status of bamboo research activities in their respective countries. The accumulated information contained in these reports constitutes the most complete review available on the state of bamboo research activities in Asia. Several papers pertaining to various aspects of bamboo cultivation and utilization were presented during the second day. These presentations were followed by discussion periods to highlight the main problems and the most urgent regional research needs and priorities.

A special session to generate ideas for improving communications and exchange of information between bamboo research workers was held during the third day. The group was also asked to prepare recommendations on specific cooperative activities and regional research topics of great priority. The proposals contained in this report reflect the consensus of those who attended the workshop; they appear before the text of the presentations because of their importance.

IDRC wishes to express its gratitude to all the people who ensured the success of this workshop and particularly to the participants who prepared papers and contributed to the discussions. It is most grateful in particular to Professor W. Liese, President of IUFRO, who enthusiastically supported the participation of IUFRO in the workshop and to Dr Omar Ali, Director of the Forest Research Institute of Bangladesh and Deputy Leader of the IUFRO Project Group on bamboo and related species who organized the program of the workshop.

The IDRC is hopeful that action will result from the workshop. In this respect, it will give serious consideration to requests from developing countries to support new initiatives and priority research projects that have good potential for increasing the social and economic benefits of rural peoples who are so greatly dependent on the availability of bamboo.

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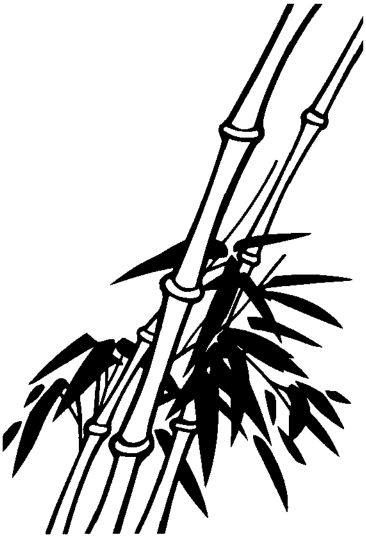

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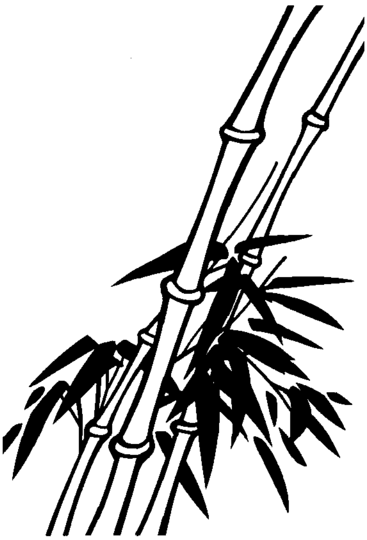


# Research Needs and Priorities

The goods and services obtained from bamboos at both the village and the national levels are of great importance in providing employment, basic human needs such as food, construction materials for shelter, and other consumer goods. Bamboos are the fastest-growing and highest-yielding renewable natural resource, but their contribution to the rural economy and support for agriculture could be further improved. Certain aspects of the properties and utilization of bamboos have been unexplored and neglected; if studied, they should provide a means to unravel the potential uses of bamboo. Currently many of the uses are limited to a few species; therefore the participants at this workshop consider it imperative that studies be extended to other, untapped or lesser-used, species.

It is recommended that research units in each country be strengthened in view of the socioeconomic importance of bamboo in the region. The following are proposed for consideration as research areas, needs, and priorities; those assigned top priority have been indicated with an asterisk.

## Taxonomy

*Classification, nomenclature, and identification of bamboos* constitute a major problem in most countries of Asia. Research workers realize that progress in resource inventory, plant breeding, information processing, etc. is adversely affected by taxonomic confusion. A taxonomic monograph of Asian bamboos is needed but will take a long time to prepare and will require a very high degree of international cooperation. Some countries are tackling this problem independently.

*In-situ conservation* is recognized as the most effective method of gene conservation. The importance of bamboos should not be overlooked in the conservation and management of nature reserves, national parks, and other forest areas.

## Silviculture and Management

The *growth habits of bamboos* must be clearly understood as an essential part of silviculture.

**Methods of silviculture and management* are well-developed for sympodial bamboos in India and Bangladesh and for monopodial bamboos in China and Japan. Such techniques have yet to be adopted in other countries of the region.

The need to manage and nurture *natural regeneration* consequent on gregarious flowering is stressed.

* *Yield studies toward quantitative assessment of bamboo resources* in each country are suggested.

The role of *nutrition and fertilization* on yield and culm properties is not well understood except for widely cultivated species. Research on fertilizer application is needed so that higher yields can be ensured.

Studies on *pests and diseases* should be intensified.

*The role of bamboos in *agriculture and forestry* is great in the provision of basic necessities to the people and in the protection of soils against erosion in hilly areas, along riversides, and on canal banks. Research on bamboo cultivation and management should be extended to cover village bamboos so that the rural economy can be maintained and upgraded.

*The development of *appropriate technologies in harvesting, storage, and transportation* should be emphasized.

## Properties of Bamboo

*Studies of *culm anatomy, physical, mechanical, and structural properties* of bamboos should be intensified and extended to the more important and economic bamboos as well as to the still untapped or lesser-used species whenever possible.

*It is important to investigate the *relationships between strength and anatomical characteristics*, especially of mature culms because at present the age at which bamboo culms are most suitable for particular uses is uncertain.

*An understanding of the *mechanical and associated properties* of bamboos as they relate to biologic and chemical composition should be pursued.

**Chemical composition of bamboos* should be analyzed in relation to their properties and their potential utilization. Their pharmaceutical possibilities should be considered as well.

An understanding of the *characteristics of the bamboo fibres* should be pursued so that the quality and strength of paper and paper products can be improved.

## Utilization

**Seasoning* of bamboos is required to promote and improve the quality of resulting products as well as to prolong their usefulness and durability. Suitable drying techniques should be explored.

*It is highly important to consider studies on the *natural durability* of bamboos.

**Traditional methods* should be explored in the search for economic methods of preservation.

**Design details in building* should be given more attention so that durability and protection can be maximized.

*Inasmuch as the benefits of *protection by nonchemical methods* are still unknown, it is necessary to collect more information about their effectiveness and to perform special tests on them.

*Studies on *economic and extensively available preservatives* should be considered, but it must be emphasized that chemical protection must be by a suitable and environmentally safe preservative in a sufficient concentration.

*The use of *economic fire retardants* for bamboos should be explored.

**Product development and improved utilization* should be pursued.

**Studies on pulp and paper,* including dissolving pulp, should be intensified and extended to all bamboo species, considering that dissolving pulp and paper from bamboo plays an outstanding role in the region.

**Architectural and structural systems* using bamboo should be further studied.

*Use of bamboos for *plybamboo, hardboard, and particle board* should be explored further.

*Utilization of *leftover bamboo stumps and biomass* for novelties should be explored.

*It is imperative to consider better uses of the tremendous waste incurred in the harvesting and processing of bamboos particularly for *energy generation* such as for firewood, charcoal and charcoal briquettes, activated carbon, and fertilizer.

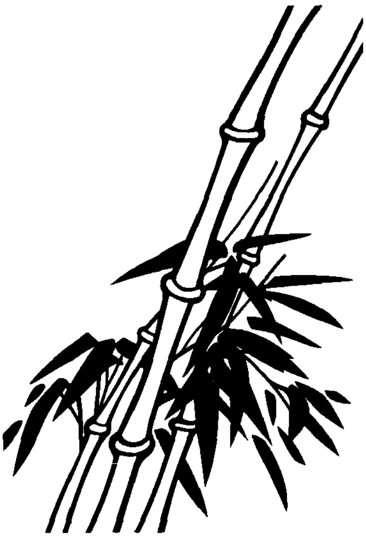
*Studies on bamboo as *food supply* should be intensified and extended to more bamboo species so that they may be used by the burgeoning local populations and be exported.

In view of the pressing need for low-cost construction, the use of bamboos for *reinforced concrete* should be encouraged, and further studies should be conducted on the long-term behaviour.

It is necessary to develop new *processing techniques and machines* so that the quality and usefulness of commercial bamboo products can be improved.

Traditional uses of bamboos for *musical instruments* in the region should be publicized, and a publication should be written with the objective of engendering improvements in them, for example, in the bamboo xylophone of Indonesia or the bamboo organ of the Philippines. Such publicity would help preserve the traditional heritage of the people in the region as well as develop the industry on a commercial basis.

A comparative study of the *service life* of bamboo materials used indoors and outdoors should be conducted with the aim of recording maintenance behaviour.



## Cooperative Activities

It is imperative that Asian countries cooperate more and more in the development of bamboos. The efforts in the past have been limited to individual scientists and have been of great value but have not led to solution of the most important problems, especially the problem of raising large-scale plantations on which all other development efforts depend. The participants recommend that:

•An information science specialist visit the bamboo research centres in the region to determine how much information is currently available, how it can be systematically collected, and which centre could be strengthened to serve as a regional resource unit providing technical information services on bamboo;

•An appropriate institution in the region undertake regular publication of a newsletter to inform scientists and researchers in the area about current research activities;

•Bamboo receive an adequate coverage in the reference journals of the Commonwealth Agricultural Bureaux and that the early literature not covered by the *Bamboo Bibliography* for 1973–78, which has served an important need in the region, be compiled and made available;

•A field guide to major useful species of bamboos of the Asia-Pacific region be produced; the most pressing need is for a well-illustrated guide that emphasizes easily recognizable vegetative characters and that includes brief notes on distribution, ecology, phenology, and utilization;

•One or more centres in the region be designated for collection, storage, and exchange of bamboo seeds and materials; Thailand should be considered for this activity because there are already facilities at the International Seed Research Centre, Huai Kaeo, Chiang Mai, and another seed centre will be established at Muak Lek, Saraburi, under the ASEAN/Canada (CIDA) forestry project; and

•Another meeting similar to this one on bamboo research be organized on the occasion of the XVII IUFRO World Congress (International Union of Forestry Research Organizations), in September 1981, in Kyoto, Japan, and that during the meeting arrangements be made for delegates to visit bamboo farms and processing facilities.

# Country Reports

# Bangladesh

All bamboo research in Bangladesh is carried out by the Forest Research Institute (FRI), Chittagong, in its four research stations in the country. To further management research, personnel have collected most of the bamboo species found or cultivated in Bangladesh and have established them in the arboretum at the FRI, and there are plans to establish similar collections in the research stations. Studies on the habit and nature of bamboo flowering, seed longevity and storage, and the behaviour of the progeny are under way. Simultaneously, there are studies on vegetative propagation with experimental material from the FRI arboretum. In the field of utilization of bamboos, studies on the density, moisture content, shrinkage, and the pulping qualities of different species are being made.

At present, all bamboo research in Bangladesh is carried out by the Forest Research Institute (FRI), Chittagong. Formerly, the forest research units for the areas now constituting Bangladesh were located in Dehra Dun, Darjeeling, Shillong, and Peshawar, which are all now outside Bangladesh. After the partitioning of British India, the Forest Research Institute, Chittagong, was established, but it began intensive research on bamboos only in 1971.

The institute has four field stations, two in the semievergreen (southeastern) regions and two in the deciduous vegetation (northern) regions of the country. In the semievergreen, bamboo is found naturally, but in the deciduous forest regions bamboo is only found where it is cultivated in the village groves.

The first work undertaken for the bamboo research program at the institute was to begin collection of all the species found or cultivated in Bangladesh and establish them in one or more arboreta at the institute and its field stations. Up to the present, the number of species collected in the field stations has been few, but renewed efforts will be financed by the Bangladesh Agriculture Research Council. At FRI headquarters, about 24 species have been collected and are growing. Recently, four more species, which are being cultivated and are growing naturally in forest regions, have come to light and are expected to be planted at the FRI arboretum soon. Also a phased research program has been planned; its first phase is to investigate the problems of propagation, which have been judged to be the most crucial.

The collection of bamboos in the FRI arboretum is of both seed and clonal origin. Seeds from all observed seedings were collected and planted, and during this process, seeding behaviour under both natural and artificial conditions was to be studied and recorded.

Since the advent of intensive research (1971), 10–12 species have produced seeds sporadically in different regions; the number of clumps involved ranged

*This paper was written as a cooperative effort of staff at the Forest Research Institute, Chittagong, Bangladesh, and was presented by S.M. Hasan.*

from a few up to 1500 scattered over forest areas of one-fourth to one-half hectare or more.

Normally, all species start flowering in February–March and continue up to May–June. Flowering occurs in three to four flushes following each other in quick succession. Both the quantity and the quality of seed produced in the first flush are the best, decreasing gradually.

Flowering habits vary among species; for instance two species, identified as *Bambusa longispiculata* Kurz and *B. nutans* Wall, produce few spikes, 3–4 at a time on branch nodes and in the axil of the leaf sheaths; seeding is poor and the branches on which spikelets are borne die soon afterward while the clump continues to grow vigorously. In contrast, in species identified as *B. tulda* Roxb., *B. blumeana* Schultes f., *B. longispiculata* Kurz, *Melocalamus compactiflorus* Bentham, and *Melocanna baccifera*, large numbers of spikelets are borne on long or short flowering shoots that emerge from culm buds and branch buds; seeding is profuse; and the entire clump dies soon afterward. In *B. vulgaris* Schrad. and another morphologically different species not yet identified, flowering is similar, and the clump dies soon afterward, although some plants die without producing seeds. In *Dendrocalamus longispathus* Kurz and *Bambusa glaucescens* Seibold ex Munro (synonym *B. nana*), some clumps behave like *B. tulda*, and others flower partially for 2–3 years, the flowered parts dying soon afterward. Seeding is profuse in the first year but very meagre in subsequent years.

There appears to be normal and out-of-phase flowering in most species. For example, in *Melocanna baccifera*, normal flowering is represented by gregarious flowering over large areas such as occurred during 1958–61 and has been reported from extensive areas in Assam, Bangladesh, and Burma. In 1974 and 1975 seeds from a few clumps were collected in Bangladesh for the FRI arboretum, which now contains the variety with a normal flowering cycle and two varieties with out-of-phase flowering. It is expected that the varieties will continue the same seeding and flowering cycle. *Bambusa tulda, Dendrocalamus longispathus,* and *Melocalamus compactiflorus* are usually found sporadically in areas of *Melocanna baccifera,* and although the gregarious seeding typical of *M. baccifera* has not yet been reported for them, sporadic flowering extending over areas of one-fourth to several hectares has been recorded during the period of study (since 1971) in Bangladesh and adjoining countries. Three seedings for *B. tulda* and four for *D. longispathus* have been recorded in different regions, and clumps raised from seeds collected there are being grown in the FRI arboretum. It is not yet clear whether these species exhibit out-of-phase seeding, but the seedings recorded so far at FRI are being considered out-of-phase. In a paper (142) contributed to the World Forestry Congress held at Jakarta, out-of-phase flowering was explained as an accidental breakdown of the physiologic shield or as a physiologic mutation. The paper postulated that the length of seeding cycle would be the same as for the normal flowering variety. On the basis of this hypothesis, a suggestion was made that all varieties producing seeds from out-of-phase flowerings be collected in special seed production areas so that seed would be available more frequently. The seeds of all species are short-lived, about 1–3 months.

The length of seeding cycles also appears to vary within each species. From seeds of *B. tulda* sown in FRI, Chittagong, a few 2–3-year-old seedlings flowered and produced seed. Of 39 clumps raised from these seeds, 16 behaved similarly, whereas the others have not yet flowered. From India similar seedings of 2–3-year-old seedlings have been reported, and three seeding cycles in

*Dendrocalamus strictus* Nees and two in *Bambusa arundinacea* Willd. have been suggested. Similarly three seeding cycles in *Oxytenanthera abyssinica* Munro have been suggested from East Africa. Based on these observations, the paper contributed to the World Forestry Congress, Jakarta, proposed that different seeding cycles are due to gene mutation as opposed to physiologic mutation suggested as an explanation of out-of-phase flowering. These genetic diversities occur in far-flung regions (142). The studies on the nature and behaviour of flowering being carried out at FRI, Chittagong, are testing these hypotheses and should provide enough information either to prove or to refute them.

There appears to be free hybridization between some species of bamboo when flowering occurs at the same time and in the same region. At the FRI arboretum, for instance, clumps grown from seed of *D. longispathus* collected from the forests have shown morphologic characters that are different from those normally found in this species. Two such variants are growing in the arboretum and have been named *D. longispathus* var. *dholai* and *D. longispathus* var. *koila*. They represent less than 0.2% of the entire population.

Studies on induced flowering have been guided by observations on flowering under natural conditions but, currently, are in a very preliminary stage. They mainly include attempts to stop vegetative growth by the removal of all emerging shoots in a season as well as all buds of the rhizomes and attempts to induce flowering by injection of 1-, 2-, and 5-ml doses of hot- and cold-water extract of 30-, 90-, and 120-day-old *Oryzia sativa* Linn. The methods of injection consist of boring holes between nodes and filling them, filling bored holes in culm walls, and injecting culm buds and the top portion of emerging culms by a clinical syringe. Removal of all emerging shoots has not produced the desired effect, as the plants continue to produce shoots endlessly. Removal of all rhizome buds, however, does stop further growth of the clumps but as yet has not resulted in any flowering. Injection of the solution in the internodes and culm walls has produced no visible effect, whereas injection into the buds or emerging shoots has produced varied reactions including the activation of dormant buds to their death and the bending of culms at the point of injection.

In the process of raising the arboretum at the institute, researchers conducted various experiments on vegetative propagation by offset planting, branch cutting, ground layering of entire culms, and aerial layering of nodes; the conclusions, briefly, are that

- Offset planting gives about 50% success, but the planting material is bulky and the amount available per clump is too low for this method of planting to be used in large-scale plantations;
- Although the bulk and the availability of branch cuttings and nodes for air or ground layering are more suitable, the success rates are less than 1%. Furthermore, it takes 6–30 months for the planting material to become established. Roots develop in 6–12 months, but the development of rhizomes takes 12–36 months. Planted material may die before root development or in the time between root and rhizome development. Workers elsewhere have tried root-promoting substances but have reported no improvement in plant establishment. The difficulty of obtaining satisfactory results with known methods of vegetative propagation together with the long period of waiting (30–36 months) militates against the adoption of this method as a technology for large-scale plantation programs.

The arboretum at FRI consists of varieties exhibiting both morphologic and physiologic variations, especially in flowering. In future, it may serve as a gene bank for the purpose of genetic studies. In the meantime, it is being used for the study of other aspects of bamboo silviculture such as culm and clump growth, taxonomy of species, etc. Sometimes, the studies at the FRI have produced unexpected benefits. For example, although the removal of emerging shoots did not induce flowering as had been hoped, instead it caused endless production of new shoots and is a suitable means for increasing the yield of edible shoots. This finding should be incorporated in a rational system of working bamboo clumps for the production of edible shoots and culms. The arboretum has also been proposed as a base for studies of yield of bamboo for both pulp production and traditional uses. The arboreta raised in the field stations will serve as replications for species trials.

At present, an urgent problem in the northern region — the death, caused by bamboo blight, of a large number of cultivated clumps — is being investigated by staff from FRI. Different fungi have been isolated from leaves, branches, and dead culms. Preliminary experiments on the control of blight have consisted of modified cultural practices and improved sanitary measures. In a separate study on the growth of clumps, it was found that about 17% of underground rhizomes are killed by fungal infection, which may end up in the rhizome stalks only, in the completely or partly damaged rhizomes, or in the damaged terminal bud of the rhizome, which does not produce any culm. This finding suggests that the dead emerging shoots, which are commonly found in all clumps, are a symptom of the blight and could be reduced by the use of fungicides in fertilizers.

At FRI, research is also being carried out on the density, moisture content, and shrinkage of *Bambusa tulda* and *B. vulgaris* and may be extended to other species. The effect of the age of culms on the fibre quality and the chemical content of *B. tulda, D. longispathus, M. baccifera, Neohouzeoua dulloa* A. Camus, and *Oxytenanthera nigrociliata* Munro has been determined for 6–36-month-old culms at 3-month intervals. It has been found that the best-quality pulp can be obtained from 6-month-old *B. tulda, M. baccifera,* and *O. nigrociliata* and from 9-month-old *D. longispathus* and *N. dulloa.* This finding has important implications for pulp production. Also, the percentages of holocellulose, alpha-cellulose, pentosans in alpha-cellulose, and total pentosans have been determined in 33-month-old *B. tulda,* 24-month-old *M. baccifera* and *N. dulloa,* and 18-month-old *O. nigrociliata* culms. The analysis in other age groups and other species is in progress.

## Future Program

Work already under way will continue for some time, and during the coming 3 years, a special study of the taxonomy and vegetative propagation by tissue-culture methods will be taken up under a scheme to be financed by the International Development Research Centre (IDRC). A preliminary study has been completed, and the conclusion is that buds are the only parts that are suitable for tissue culture. All culm buds in bamboos are multiprimordial, and each primordium consists of a rhizome-like structure.

The entire primordial structures will have to be used for tissue-culture trials. The location and the size of the primordium may be used as variables in the trials.

# India

India has rich bamboo resources. With about 20 genera and more than 100 species spread over an area of 9.57 million hectares, perhaps the world's largest reserves of bamboos exist in this country. Areas particularly rich in bamboos are the northeast region, Western Ghats, and the Andamans. The annual output of bamboos in the country is about 3.23 million t and more than half of this production is consumed by the paper industry.

Flowering in bamboos is rather erratic and varies between the physiologic extremes of constant flowering and constant sterility as evidenced by *Bambusa atra* and *B. vulgaris* respectively. The majority of bamboos fall between these two extremes and represent a wide range of flowering cycles of several to many years.

Cultivation of bamboos is done by seed or offsets, in some cases by cuttings or layers. As seeding years are scarce, propagation by vegetative methods is quicker.

Management of bamboos is based on the physiologic development of the clumps. The new culms are produced from the rhizomes along the periphery of the clumps. Although the culms attain their maximum size in one season, these are not ready for utilization until about 2 or 3 years, because of lack of strength. The yield of bamboos varies considerably depending upon the intensity of stocking and biotic interference. It varies between 0.2 and 4.0 t per hectare and in most cases is not very encouraging. The two major considerations in the management of bamboo areas are the felling cycle and the felling intensity. Too short a felling cycle brings about deterioration of the clump, whereas a long felling cycle may result in overcrowding.

The number of ways bamboos enter into the diverse phases of human life is well known. Some of the conventional uses and those brought to light by modern technological advances are discussed. India leads the Asian countries in the utilization of bamboos for paper manufacture, which is the most important industrial use of this raw material. Approximately 2 million t of air-dried bamboo are at present being utilized in India for paper making. Although India has nearly 100 species of native bamboos, only about 10 species are being commercially exploited.

The present revenue derived from bamboo resources, which is estimated at Rs 66.776 million per annum (U.S. $8.53 million), can be increased if bamboo industries are developed along the right lines.

Most bamboos flower only once in their lifetime and die soon after. This phenomenon poses a special problem in bamboo identification, as taxonomic differences in plants are primarily based upon reproductive structures. Recently, however, a breakthrough has been made by the Forest Research Institute (FRI) whereby certain vegetative structures, such as

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qualitative characters of culm sheaths and juvenile vegetative buds can be successfully used in bamboo identification without reference to flowers. The details of this work are presented.

The cytology of most bamboos is not well known, but many species studied so far are tetraploids; *Dendrocalamus* and Asiatic species of *Bambusa* are hexaploids. There is an urgent need for cytologic work on Indian bamboos.

The practice of bamboo silviculture has been strongly developed in India. However, these activities have been mainly confined to *Dendrocalamus strictus* — the commonest Indian bamboo — but they nevertheless should provide a useful background for the design of similarly oriented studies on other species.

For proper use of bamboos for constructional purposes, their physical and mechanical properties have been studied and the methods of test standardized.

Recently, bamboo has been successfully used as a reinforcing material, replacing steel, in various concrete constructions, such as roof slabs, beams, electric posts, etc. The economy achieved is 33% over that for steel-reinforced constructions. At present 66% of the pulp used in making paper in India comes from bamboo, and there are 30–35 factories in the country that make paper from bamboo pulp. In many respects, bamboo offers advantages over wood as a raw material for paper making.

Future research on bamboos in India will lay emphasis, apart from silvicultural management, on certain hitherto neglected fields such as cytology, physiology of flowering, variation in seedling progeny, and the use of sophisticated methods of vegetative propagation like tissue- and shoot-culture techniques. On the utilization side, studies on anatomy, fibre characteristics, pulping and paper-making qualities, etc. should be extended to as many different species as possible. To initiate work on genetic upgrading of bamboos, FRI will shortly be launching a scheme under which work on germ-plasm collection, conservation, and evaluation for genetic improvement of Indian bamboos will be undertaken on a priority basis. The scheme will have three field stations in the country — one each in the East, North, and South for temperate, subtropical, and tropical species respectively — for exploration and collection of bamboo germ plasm representing about 100 species occurring wild in India under different climatic conditions. The studies will include growing the species in gene banks for evaluation and further utilization in research.

India is endowed with a large number of bamboo species, and perhaps the world's largest reserves of bamboos exist in this country. Of a total of nearly 1000 known species (excluding the herbaceous bambusoid grasses), about 100 have already been described or recorded from India, and there are probably many more that are not yet known to science. Several species have also been introduced from other countries, and at present the total number of known taxa both wild and cultivated in India is about 113. Of these, more than 50% occur in eastern India — Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, and W. Bengal. Other areas rich in bamboos are Andamans, Bastar region of Madhya Pradesh, and Western Ghats, and quite a few species are found in other parts of India both in the hills as well as in the plains.

The 19 principal genera of bamboos (of a total of roughly 50 in the world) occurring in India are *Arundinaria, Bambusa, Cephalostachyum, Chimonobambusa, Dendrocalamus, Dinochloa, Gigantochloa, Indocalamus, Melocanna, Neohouzeoua, Ochlandra, Oxytenanthera, Phyllostachys, Pseudostachyum, Schizostachyum, Semiarundinaria, Sinobambusa,* *Teinostachyum*, and *Thamnocalamus*. Besides, two exotic genera — *Pseudosasa*, and *Thyrsostachys* — are found in cultivation. This list should be considered only tentative because there are some described genera that may prove synonymous with others, and there may be a few more that have not been enumerated here.

A conservative estimate is that the forest area under bamboos in India (including plantations) is 9.57 million hectares, or about 12.8% of the total forest area of the country. The estimated annual output of bamboos (air-dried) is 3.23 million t, one-fifth of the country's total wood production and is utilized for conventional as well as highly sophisticated purposes. More than half of the production (about 2 million t) is consumed by the paper and rayon industries alone. Bamboos, therefore, constitute one of the most important renewable natural resources of India.

## Distribution

In India, bamboos have an extremely wide range of distribution and are found as an understory in many types of forests in all the states except Jammu and Kashmir. They form rich belts of vegetation in well-drained parts of tropical and subtropical habitats and grow at altitudes up to 3700 m in the Himalaya. An alphabetic list of the taxa found either wild or in cultivation in India, together with their distribution is given in Table 1.

Table 1. Species and location of bamboos in India.[a]

| Species | Location |
|---|---|
| *Arundinaria clarkei* | Manipur and adjoining areas |
| *A. gracilis* | E. Himalaya |
| *A. hirsuta* | Khasi, Naga hills 1525-3000 m |
| *A. maling* | N. Bengal, Sikkim, Arunachal Pradesh 1800-2750 m |
| *A. mannii* | Jaintia hills 900 m |
| *A. microphylla* | Sikkim, Khasi hills 2400-3100 m |
| *A. racemosa* | N. Bengal, Sikkim, Arunachal Pradesh 3000-3660 m |
| *A. rolloana* | Naga hills 1525-2300 m |
| *A. suberecta* | Sikkim, Khasi, and Jaintia hills 1200-1500 m |
| **Bambusa arundinacea* | Throughout India in the plains, ascending to 1250 m; commonly cultivated in N.W. India in the plains |
| *B. atra (B. lineata)* | Andaman Islands in marshy coast forests (Rutland Island); also in Malaya |
| **B. auriculata* | Assam; cultivated at Calcutta and Dehra Dun |
| **B. balcoa* | Eastern Uttar Pradesh, Bihar, Bengal, Assam, and Arunachal Pradesh up to 600 m |
| **B. burmanica* | From Burma; frequently cultivated |
| **B. copelandii* | From Burma; cultivated at Calcutta and Dehra Dun |
| **B. glaucescens (B. multiplex, B. nana)* | From China and Japan; frequently cultivated as a hedge in tea gardens of Assam and elsewhere |
| *B. khasiana* | Khasi, Jaintia, and Naga hills, Manipur up to 1250 m |
| **B. longispiculata* | Meghalaya; cultivated at Calcutta and Dehra Dun |
| **B. mastersii* | Assam (Dibrugarh) |
| **B. nutans* | Sub-Himalayan tracts from Jamuna eastward (Assam, Bengal, Sikkim, Arunachal Pradesh 600-1500 m); commonly cultivated in N.W. India |
| **B. oliveriana* | From Burma; cultivated at Calcutta and Dehra Dun |
| *B. orientalis* | Orissa (Ganjam, Bengal) |
| **B. pallida* | N. Bengal, Sikkim, Arunachal Pradesh, Khasi hills up to 1250 m |
| **B. polymorpha* | Bengal, Assam, etc. |
| *B. schizostachyoides* | S. Andamans |

*(continued)*

*(Table 1 continued)*

| Species | Location |
|---|---|
| **B. spinosa* | Circars and the hills of S. India; cultivated at Calcutta and Dehra Dun |
| *B. teres* | Bengal, Assam, etc. |
| **B. tulda* | Wild in E. India and N. Circars 450-600 m; widely cultivated in the plains and foothills of N. India |
| **B. ventricosa* | From China and Japan; frequently cultivated for ornament |
| **B. vulgaris* | Pantropical (origin unknown); frequently cultivated; has run wild in warmer areas |
| **B. vulgaris* var. *stricta* | Pantropical; commonly cultivated for ornament |
| *Cephalostachyum capittatum* | Sikkim, Arunachal Pradesh, Meghalaya 600-2450 m |
| *C. capittatum* var. *decomposita* | Sikkim |
| *C. flavescence* | Andaman Islands (also Burma); cultivated at Calcutta |
| *C. fuchsianum* | Arunachal Pradesh, Naga hills 1800-2450 m (also in Bhutan) |
| *C. latifolium* | Sikkim, Arunachal Pradesh, Naga hills, Manipur up to 2300 m (also in Bhutan) |
| *C. pallidum* | Arunachal Pradesh, Khasi hills, Manipur up to 1500 m |
| **C. pergracile* | Bihar, Assam, Naga hills, Madhya Pradesh, Arunachal Pradesh; frequently cultivated (common in Burma) |
| *Chimonobambusa callosa (Arundinaria callosa)* | Arunachal Pradesh, Khasi hills 1200-2280 m |
| *C. densifolia (A. densifolia)* | Anamalai hills 2600 m (smallest Indian bamboo) |
| *C. falcata (A. falcata)* | W. Himalaya from Ravi to Nepal 1200-2300 m |
| *C. griffithiana (A. griffithiana)* | Arunachal Pradesh, Naga, Khasi, and Jaintia hills 900-1372 m |
| *C. hookeriana (A. hookeriana)* | Sikkim, Arunachal Pradesh, Khasi hills 1200-2450 m |
| *C. intermedia (A. intermedia)* | Sikkim, Arunachal Pradesh, etc. 1200-3050 m |
| *C. jaunsarensis (A. jaunsarensis, A. anceps)* | Himalaya from Jaunsar through Chamoli in Garhwal to the source of Pindar River in Kumaon 1800-3300 m |
| *C. khasiana (A. khasiana)* | Sikkim, Khasi hills 1525-1830 m |
| *C. polystachya (A. polystachya)* | Sikkim, Khasi hills, etc. 900-1500 m |
| **Dendrocalamus brandisi* | Native of Burma; cultivated at Calcutta, Dehra Dun, and in Andamans |
| **D. calostachyus* | Native of Burma; cultivated at Calcutta and Dehra Dun |
| *D. collettianus* | Native of Burma; cultivated at Calcutta |
| **D. giganteus* | Native of Malaya and Burma; frequently cultivated |
| **D. hamiltonii* | West Central, and East India in the lower hills from Simla eastward extending to Upper Burma, up to 900 m (perhaps only in cultivation west of Nepal) |
| *D. hookeri* | E. Himalaya; Khasi, Jaintia, and Naga hills 600-1500 m; cultivated in W. Himalaya (Garhwal, Kumaon) |
| *D. hookeri* var. *parishii (D. parishii)* | Himachal Pradesh |
| **D. longispathus* | Bengal and other parts of E. India |
| **D. membranaceus* | Native of Burma; cultivated at Calcutta and Dehra Dun |
| *D. patellaris* | N. Bengal, Sikkim, Naga hills, Arunachal Pradesh 1200-1500 m |
| *D. sikkimensis* | Sikkim, Arunachal Pradesh, Garo, and Naga hills 1200-1850 m |
| **D. strictus* | Deciduous forests all over India except in N. Bengal, Assam, and moist regions of the west coast; commonly cultivated throughout India in the plains and foothills |
| *D. strictus* var. *argentea (Bambusa stricta* var. *argentea)* | Rare; only seen in cultivation |
| *D. strictus* var. *prainiana (D. prainiana)* | Bengal |
| *D. strictus* var. *sericea (D. sericeus)* | Mt. Parasnath (Hazari Bagh), Bihar; also in Chhota Nagpur and Bengal |
| *Dinochloa andamanica (D. tjankorrh* var. *andamanica)* | Andaman and Nicobar islands; very common; often climbing on tallest trees |
| *D. compactiflora (Melocalamus compactiflorus)* | Bengal, Assam, Meghalaya up to 1850 m |

*(continued)*

*(Table 1 continued)*

| Species | Location |
|---|---|
| **D. mcclelandii* | Bengal, Assam, Burma, etc.; cultivated at Dehra Dun |
| *Gigantochloa atter* | Native of Malaya; cultivated at Calcutta |
| **G. atter* (black mutant) | From Malaya; cultivated at Calcutta and Dehra Dun |
| *G. macrostachya* | Assam, Garo hills, etc. |
| *G. tekserah* | Garo hills |
| *G. verticillata* | Native of Malaya and Burma; cultivated at Calcutta |
| **Guadua angustifolia* | Native of tropical America; cultivated at Dehra Dun |
| *Indocalamus walkerianus* (*Arundinaria walkeriana*) | Pulney hills in S. India 1500 m |
| *I. wightianus* (*A. wightiana*) | Nilgiri, Palghat, and Tinnevelly in S. India 1800-2600 m |
| *I. wightianus* var. *hispidus* (*A. wightiana* var. *hispida*) | Nilgiri hills 2100-2300 m |
| **Melocanna baccifera* (*M. bambusoides*) | Bengal, Assam, Meghalaya, Tripura, Mizoram, and other parts of E. India in the plains and lower hills; cultivated elsewhere |
| *M. humilis* | Native of Burma; cultivated at Calcutta |
| **Neohouzeoua dulloa* (*Teinostachyum dulloa*) | N. Bengal, Sikkim, Khasi, and Jaintia hills; cultivated at Calcutta and Dehra Dun |
| *N. helferi* (*T. helferi*) | Garo, Khasi, and Jaintia hills 900-1250 m |
| *Ochlandra beddomei* | Wynaad in Malabar |
| *O. ebracteata* | Parithipally Range, Kottur Reserve, Trivandrum Division, Kerala |
| *O. scriptoria* (*O. rheedei* | West coast, Malabar, Kerala at low elevations on riverbanks |
| *O. setigera* | Nilgiri hills at Godalur 900 m |
| *O. sivagiriana* (*O. rheedii* var. *sivagiriana* Gamble) | Pulney and Sivagiri hills 1200-2400 m |
| *O. talbotii* (*O. rheedii* var. *sivagiriana* Talbot) | N. Kanara on the riverbanks |
| *O. travancorica* | Plains and hills of S. India in Kerala and Tinnevelly up to 1550 m |
| *O. travancorica* var. *hirsuta* | Kerala hills |
| *O. wightii* (*O. brandisii*) | Tinnevelly Ghats at Courtallum (Kerala hills) at low elevations and up to 1100 m |
| **Oxytenanthera albociliata* | Native of Burma; widely cultivated in Bengal and elsewhere |
| **O. abyssinica* | Rocky hills of Sudan and other parts of Africa; cultivated at Dehra Dun |
| *O. bourdillonii* | Ghats of Kerala 900-1550 m |
| *O. monadelpha* (*O. thwaitesii*) | Hills of Kurnool, hills of W. Ghats from Nilgiri southward 1050-1850 m |
| **O. nigrociliata* | Bihar, Orissa, Garo hills, Coorg, S. Kanara, Andaman and Nicobar islands |
| *O. ritchevi* (*O. monostigma*) | West coast, W. Ghats from Konkan to Anamalai hills; rare |
| *O. stocksii* | Konkan coasts, Ghats of N. Kanara; usually cultivated |
| *Phyllostachys assamica* (*P. bambusoides* sensu Gamble) | Arunachal Pradesh 2400 m |
| **P. aurea* | From Japan; cultivated at Dehra Dun and Mussoorie |
| *P. bambusoides* | Sarahan, Upper Bashahr, Himachal Pradesh 2438 m; introduced from China/Japan; has run wild |
| *P. mannii* | Naga hills; cultivated in Khasi hills 1500 m |
| *P. puberula* | From Japan; cultivated at hill stations of India |
| *Pseudosasa japonica* (*Arundinaria japonica*) | From Japan; cultivated in E. Himalaya (Darjeeling, etc.) |
| *Pseudostachyum polymorphum* | N. Bengal, Sikkim, Garo, and Naga hills, Manipur up to 900 m |
| *Schizostachyum brachycladum* | Native of Malaya; cultivated at Calcutta |
| *S. rogersii* | Andamans |

*(continued)*

*(Table 1 concluded)*

| Species | Location |
|---|---|
| *Semiarundinaria pantlingii* (*Arundinaria pantlingii*) | Arunachal Pradesh 3000-3350 m (also in Bhutan) |
| *Sinobambusa elegans* (*Arundinaria elegans*) | Naga hills 1525-2300 m |
| *Teinostachyum beddomei* (*T. wightii*) | Slopes of W. Ghats from N. Kanara to Cape Comorin 900-1550 m, Nilgiri |
| *T. griffithii* | Assam, Meghalaya, Arunachal Pradesh |
| *Thamnocalamus aristatus* (*Arundinaria aristata*) | C. Himalaya to Arunachal Pradesh 2700-3350 m |
| *T. falconeri* (*A. falconeri*) | Jaunsar to Arunachal Pradesh 2250-2750 m |
| *T. prainii* (*A. prainii*) | Naga and Jaintia hills 1000-2240 m |
| *T. spathiflorus* (*A. spathiflora*) | W. Himalaya from Satlej through Nepal to Arunachal Pradesh 2250-3050 m |
| **Thyrsostachys oliveri* | Native of Burma; cultivated at Calcutta and Dehra Dun |
| *T. siamensis* | Native of Burma and Thailand; cultivated at Calcutta and elsewhere as a hedge plant |

[a]Species and varieties marked with an asterisk are available in the live collection at Forest Research Institute, Dehra Dun.

## Ecology

India is divided into five major bioclimatic regions — the alpine region; temperate region; subtropical region; tropical, moist region; and dry, tropical region. The distribution of various genera and species of bamboos is different from one region to another, that is to say that, with the exception of a few overlaps here and there, certain bambusoid taxa are more or less characteristic of forest types and ecological situations.

The alpine vegetation of India consists of alpine deserts, scrubs, meadows, and forests, occurring throughout the Himalayan mountains at altitudes higher than 3050 m. The status of alpine meadow is doubtful, and it may have been partly shaped by biotic rather than climatic features. The alpine vegetation of India is believed to contain a number of plants that are common to alpine regions of Europe. However, there are no native bamboos in the whole of Europe. There are plants from central Asia, Tibet, and Japan with several bambusoid elements present in the alpine belt of the Himalaya. Only a limited number of bamboo species, such as *Arundinaria microphylla, A. racemosa, Chimonobambusa jaunsarensis, Semiarundinaria pantlingii,* and *Thamnocalamus aristatus* are found in this region.

The temperate forests of India are mainly distributed in the states of Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, West Bengal, and Arunachal Pradesh in the north, and Tamil Nadu in the south. The main climatic feature of this region is extremely low temperatures in the winter, often below freezing. The temperature is determined more by altitude than by latitude. Generally a rise in the altitude by 270 m accounts for a fall of 1 °C in mean temperature. The northern temperate forests have been classified into wet, moist, and dry types and occur between 1500 and 3050 m. The mean minimum temperature during the three winter months of December–February is near freezing. Annual rainfall is 2000 mm or more, with November–March being rather dry and July having 750 mm or more rain. Dense mist prevails during the monsoons and is the characteristic climatic feature of this region. Principal bamboos growing wild in this region are *Arundinaria, Chimonobambusa, Phyllostachys, Semiarundinaria, Sinobambusa,* and *Thamnocalamus*. The southern temperate forests cover the higher hills of Tamil Nadu and Kerala from about 1500 m upward and are popularly called *sholas*. The *sholas* are evergreen forests of close canopy and are generally developed in sheltered sites on steep slopes. The climate here is very equable and the region gets rainfall from both the monsoons. The flora is varied and includes both tropical and temperate elements. The main bamboos found here are species of the genera *Bambusa, Chimonobambusa, Dendrocalamus, Indocalamus,* and *Oxytenanthera*.

Just above the submontane tropical forests and below the cooler temperate forest zone, the principal subtropical zone forms a crescent-shaped band sweeping right along the length of the Himalaya and the adjoining chain of hillocks from Jammu and Kashmir to Arunachal Pradesh. Though it is mostly confined to outer Himalaya, the zone penetrates deep into the inner valleys. This zone also encompasses the upper reaches of the Khasi, the Jaintia and nearby hills, the higher hill tops of the central Indian highlands, and the annular rings circumscribing temperate areas of higher hill tops of south India. The altitude of the zone ranges roughly from 1000 to 2000 m. Being defined by climatic and floristic components, which themselves depend upon a number of factors, the upper and lower limits show considerable fluctuations. As the latitude falls, the zone is shifted higher. The main subtropical bambusoid genera are *Arundinaria, Bambusa, Cephalostachyum, Chimonobambusa, Dendrocalamus, Dinochloa, Gigantochloa, Indocalamus, Neohouzeoua, Ochlandra, Pseudostachyum, Sinobambusa,* and *Thamnocalamus*.

The tropical, moist region is divided into tropical, wet evergreen; tropical semievergreen; tropical, moist deciduous; and littoral and swamp forests. Tropical, wet evergreen forests are distributed throughout the tropical portion of the country wherever the rainfall is high except on precipitous slopes and rapidly draining soils. They are most extensive along the Western Ghats in Maharashtra, Karnataka, Tamil Nadu, Andamans, W. Bengal, and Assam. Bamboos are usually present in the wet, evergreen area of the northeast. Tropical semievergreen forests are subdivided into southern and northern types. The former is intermediate between the tropical evergreen and tropical, moist deciduous forest types. Its distinction is rather difficult on account of the presence in patches or groups of taxa characteristic of the two other types. As a climax formation, it is well-marked only on the Western Ghats, which are rich in bamboos. The northern tropical semievergreens are better developed than the southerns and are found in Meghalaya, N. Bengal, and Orissa in areas with heavy rainfall where bamboos may or may not be present. Tropical, moist

*Forest Research Institute, Dehra Dun.*

deciduous forests cover a large part of India and occur in almost all the states, such as Andamans, Andhra Pradesh, Assam, Arunachal Pradesh, Bihar, Gujarat, Kerala, Karnataka, Maharashtra, Madhya Pradesh, Orissa, Tripura, Uttar Pradesh, and W. Bengal. Though there is general similarity in climate, rainfall and locality factors vary widely in these areas, which are well represented by various bamboo species. Littoral and swamp forests are of two types, littoral and tidal swamp forests. Littoral forests are found on sandy beaches and dunes along the seashore. The temperature is moderated by the proximity of the sea and the sea breeze. Rainfall varies with locality from 760 to more than 5000 mm. The tidal swamp forests are characterized by mangrove scrubs, and *Bambusa atra (B. lineata)* of Andamans is representative of this region. Other bamboos found in the tropical, moist region are the species of genera *Bambusa, Cephalostachyum, Dendrocalamus, Melocanna, Ochlandra, Oxytenanthera, Schizostachyum,* and *Teinostachyum*.

Forests in the dry, tropical region are distributed from the edge of the Himalayan foothills to Cape Comorin bounded by the Rajasthan desert on the northwest, Western Ghats on the southwest, and on the east by the wetter forests of Bengal. The rainfall varies between 250 and 1250 mm, and the dry season persists for about 6 months a year. These forests have suffered considerable destruction by human interference over time, and, today, they have a very uneven and unbalanced spatial distribution; large areas either are devoid of vegetation or carry only a maltreated crop. The region is prone to erosion and drought in the hilly parts; it can be further subdivided into tropical, dry deciduous forests; tropical thorn forests; and tropical, dry evergreen forests. *Bambusa arundinacea* and *Dendrocalamus strictus* are the two main bamboo species of this region, both of which have a wide distribution. Also, *Cephalostachyum pergracile* is common, and some other genera and species are present.

## Flowering

The duration of the vegetative state and the incidence of flowering in bamboos vary from one species to another. In some bamboos — *Bambusa vulgaris*, for example — the vegetative state shows signs of persisting indefinitely, the plants producing new growth with undiminished vigour year after year. Perhaps such bamboos possess a physiologic stability that keeps them perpetually in a vegetative state, only occasionally permitting individual plants under certain circumstances to produce flowers.

Never, since *B. vulgaris* was described in 1810, has it been observed to flower gregariously. Each occurrence of flowering has involved at most only a few plants; the flowers so produced are reported not to have set seeds, and, therefore, no seedling progenies have been available. However, in spite of its not having rejuvenated in recent times by sexual reproduction, *B. vulgaris* remains to this day one of the most vigorous of all known bamboos.

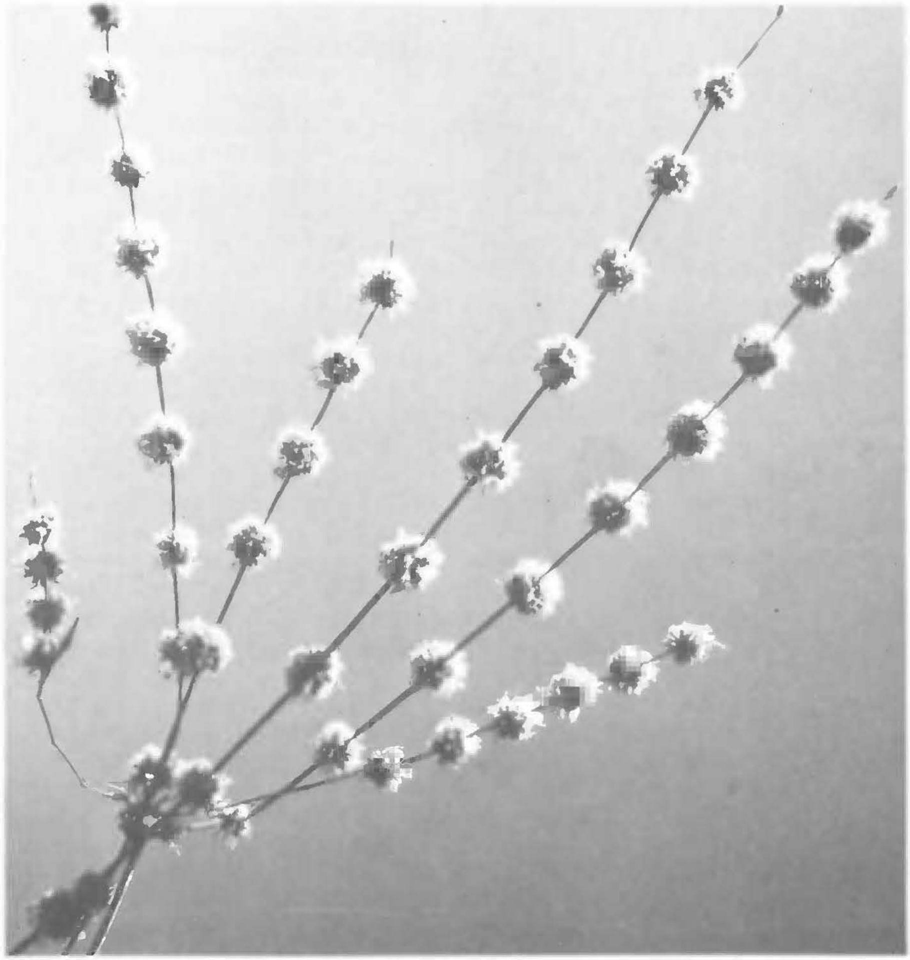
In contrast to this potential sterility in some bamboos, others have a persistent tendency to flower. *Bambusa atra (B. lineata)* of Malaya and Andamans, for example, is often described as a constant-flowering species. Unlike other bamboos where the culms that produce flowers die after flowering, its stems do not die; rather they remain healthy and green.

The majority of bamboos for which records are available fall between these two physiologic extremes (constant flowering and constant sterility) by flowering at intervals of several to many years. Individual kinds are not always consistent in their flowering habits, but two general modes are distinguishable. Some bamboos die within 1 or 2 years of flowering, e.g., *B. arundinacea,* whereas others such as *Phyllostachys* and some *Arundinaria,* do not die. Instead their growth slows down during flowering. To think clearly about the ontogeny of a bamboo plant, therefore, one must distinguish between the life cycle and the flowering cycle, because the two may not be coextensive. The flowering cycle in bamboos has been a matter of much popular interest and speculation. Published accounts giving length of flowering cycle for particular species are rather numerous. From this evidence many bamboos appear to have a more or less sharply defined flowering cycle of roughly 1, 3, 7, 11, 15, 30, 48, 60, or possibly even 120 years, at the end of which time all plants of a given seedling generation flower gregariously.

There is a common belief that gregarious flowering in most bamboos, which takes place only once in their lifetime, is comparable to the working of an alarm clock. If the alarm is set to go off at a particular time, all populations of a given species raised from the same seed source, no matter where they are situated, start flowering at the same time. *Thyrsostachys oliveri* flowered in Burma in 1891. Seeds were sent to Calcutta and Dehra Dun, approximately 1500 km apart, and the clumps, which were raised at both the places, flowered simultaneously in 1940. More recently in 1961, simultaneous flowering of *Melocanna baccifera* was observed in Assam and Dehra Dun, more than 2000 km apart. This event aroused a lot of interest in botanic and forestry circles. *Bambusa arundinacea,* which flowered almost throughout India in 1970–71, after a gap of 45 years is yet another example of this strange phenomenon. However, these records of flowering dates are in no case documented by personal observation of the complete cycle in a single hereditary line from seed to seed. A scientific approach to the study of flowering cycles in bamboos, therefore, calls for the frank recognition of one hard fact: that existing records do not provide a positive basis for the generally held assumption that some bamboos have, as an innate character, a flowering cycle of precise and invariable length. But still it is a fact that when they do flower gregariously, the flowering is so profuse that the whole plant from top to bottom is transformed into a gigantic inflorescence. Also, it seems as if, before its death, the bamboo sacrifices everything for the production of its offspring. The factors that determine gregarious flowering are not clearly understood. Certain evidence points to the probability that a short rainy season followed by a spell of severe drought stimulates flowering. This probability also explains why bamboo flowering is commonly associated with local famines.

On the basis of their flowering behaviour, bamboos can be classified into three groups — those that flower annually or nearly so, those that flower gregariously and periodically, and those that flower sporadically or irregularly. However, a given species may manifest behaviour that places it in more than one of these groups. *Dendrocalamus strictus,* for instance, falls within both the second and the third groups, as it is known to flower both sporadically almost every alternate year and gregariously at long intervals of 20–65 years. It is clear, therefore, that periodic flowering is not the universal rule, nor is it invariable in those species where it is the general rule.

The period between two gregarious flowerings over the same area for a species is often called its physiologic cycle. This cycle is more or less constant for a given locality but differs in locations remote from one another and with appreciable climate and soil differences. FRI data indicate that the physiologic cycles of some of the bamboos are *Bambusa arundinacea* 30–45 years, *B. copelandii* 48 years, *B. polymorpha* 35–60 years, *B. tulda* 30–60 years,



*Dendrocalamus strictus in flower.*

*Chimonobambusa falcata* 28–30 years, *C. jaunsarensis* 45–55 years, *Dendrocalamus hamiltonii* 30–40 years, *D. strictus* 20–65 years, *Melocanna baccifera* 30–45 years, *Ochlandra travancorica* 7 years, *Oxytenanthera abyssinica* 30 years, *Phyllostachys bambusoides* 60 years, *Thamnocalamus falconeri* 28–30 years, *T. spathiflorus* 16–17 years, and *Thyrsostachys oliveri* 48–50 years.

## Cultivation and Plantation

Cultivation of bamboos is done by seed or offsets, in some cases by cuttings or layers. If the seed is good, it germinates easily, and seedlings are reared and transplanted in the field. As general seeding years are scarce, it is necessary to wait for seed, and therefore propagation by offsets is quicker. In species like *Dendrocalamus strictus* and *D. hamiltonii*, in which seeding takes place both sporadically and at long intervals, sporadic flowerings give very little if any

*A portion of a Dendrocalamus strictus plantation.*

fertile seed, so that it is necessary to wait for general flowerings, as with the rest. Offsets consist usually of a portion of old culm with its roots, cut off above a joint at about 30–60 cm above the ground, and the shoots come from dormant buds at the base of the culm. Such offsets are best taken and planted in the season of rest, so that the season of active vegetation, which usually begins with the rains, may find them well in position and capable of taking root easily. Offsets taken in the late rainy season after the new growth has started usually fail. Cuttings are normally made by planting one or more internodes, the lowest bearing root buds capable of growing; layers, the more usual method of propagation with some species, e.g., *Bambusa vulgaris*, are partly cut culms laid in the ground so that they may take root at nodes. When the shoots have appeared, the internodes are cut and the layers planted separately. *B. vulgaris* is one of the easiest bamboos to grow; it can even be propagated by direct stump planting.

The transplanting of offsets should be carried out immediately before the beginning of the rainy season, and watering should be done in dry weather. A new shoot is produced sometimes in the first year, sometimes not until the second year. Vegetative methods of reproduction have one major drawback: the resulting clumps flower when the parent clumps flower and so their life may be short or uncertain. Propagation, therefore, is best done from seed. Direct sowings have been successful, as have the transplantings of nursery seedlings. Great care is required when the seedlings are transplanted because they are likely to wither if their roots are exposed to the sun. To reduce mortality, many cultivators raise seedlings in polythene bags. Although 2-year-old seedlings establish quickly, their raising is time-consuming and expensive as shown by experiments conducted on *Dendrocalamus strictus* and *D. longispathus*. Hence, now, the practice is to plant 1-year-old nursery-raised seedlings.

Experiments conducted at FRI, during 1962–63 and 1974–75, on *Bambusa polymorpha* and *Dendrocalamus strictus*, have indicated that stem cuttings could be used for vegetative propagation. April was found to be the best month for the preparation of two-node cuttings. It was also observed that horizontal planting was superior to vertical and oblique methods. A study of the possibility of raising bamboo plants from branch cuttings after pretreatment with substances like molasses is under way.

Bamboo plantations, of mainly *Dendrocalamus strictus*, are being raised by different state forest departments, but these face two main problems: availability and viability of seed and protection of plantation areas. A solution to the first problem has been found at FRI with the development of a suitable method of storage to prolong seed viability. *D. strictus* seed can be stored over silica gel or anhydrous calcium chloride in a desiccator or at 3–5 °C ambient temperature after reduction of its moisture content to 8%. Seed lots with 67% germination capacity were stored under these three conditions and exhibited 51, 54, and 59% germination respectively after 34 months. Study has also indicated the presence of a postripening period in the seed, which is overcome by storage under favourable conditions.

Protection of bamboo plantations is most vital. At the first stage, seedlings are dug out by wild pigs who eat away tender rhizomes. At the second stage, cattle damage to seedlings is heavy. Villagers also hack the young plants to get what is useful to them, leaving behind a bushy growth that has no potential. In Vindhyan tract, for example, large-scale bamboo plantations were tried in the past. Most of these plantations now comprise bushy clumps scattered far apart. In "agro-silvics," where each plant receives individual care, bamboo is full of promise.

Yield from bamboo, especially for widely planted *D. strictus*, is not very encouraging. Planting at 5 × 5 m spacing may produce annual yields of 3.5 t/ha.

## Management

Management of bamboos is based on the physiologic development of the clumps. The new culms are produced from the rhizome generally along the periphery of the clump. Although the culms attain their maximum size in one season, these are not ready for utilization because they lack strength. Further, for proper development of new culms and their support, a certain number of culms 1 or more years old have to be left. Thus, although bamboos behave like an annual crop, it is not possible to harvest all the culms annually.

In *Dendrocalamus strictus* the culms are almost if not entirely solid in dry localities. Likewise, in *Thamnocalamus prainii*, which is a small, wiry climbing bamboo, the culms are usually if not always solid. But for these exceptions, the culms of bamboos are hollow with walls varying in thickness. In some species like *Thyrsostachys oliveri* and *Melocanna baccifera* the culms are devoid of branches for a considerable height or have only very small branchlets. Some bamboos like *Oxytenanthera albociliata* and *Dendrocalamus hamiltonii* have prominent branches, whereas others like *Bambusa arundinacea* have dense clusters of branchlets at the nodes all the way up the stem, the clusters being almost arranged alternately. In *B. arundinacea* the branchlets are thorny. Some species like *D. strictus,* which are usually deciduous, are seen to be evergreen in habit in moist situations, and others like *B. polymorpha,* which are ordinarily evergreen, may develop a deciduous habit in dry climates. Rhizomes of bamboos are of two kinds. Some are short, knotty, thick, solid outgrowths that form a tangled mass, as is seen in most Indian species, whereas others are runner-like and spread over a wide area as in *Melocanna baccifera.* New culms appear at the commencement of the principal rainy season in the form of cones that are covered with overlapping sheaths inserted at the nodes. The culms develop rapidly, reaching their full height in about 2–4 months. Branches develop only after the growth in height is complete. Two kinds of buds are observed on the rhizomes, scaly, pointed buds and flat buds. The former develop into rhizomes and the latter into culms. The scaly buds are formed during the summer months and the culm buds develop during the winter months. The culm buds emerge from the soil with the early rains and grow rapidly. It is mostly the youngest rhizomes that produce the culms; they give rise to scaly, pointed buds or flat buds, seldom simultaneously.

Bamboos in general, and those that flower at long intervals in particular, die after the seeding is over. Subsequent regeneration appears in the ensuing rainy season, but the new plant takes some years to mature into full-sized clumps. In the case of sporadic flowering, only the culm that flowers dies. Culms of any age may flower depending on the conditions. In the case of gregarious flowering, the whole clump dies; the rhizome from which the culms arise also dies after the ripe seeds have fallen.

The stocking of bamboo in nature is very variable (Table 2). The areas could roughly be classified into four categories:

•Dense or pure — areas having more than 125 mature, well-developed clumps per hectare, i.e., bamboo clumps found almost to the exclusion of trees or large shrubs;

•Predominant — areas having 50–125 mature clumps per hectare, i.e., the bamboo clumps dominating the tree growth;

•Sparse — areas having 25–50 clumps per hectare and many trees; and

•Poor and scattered — areas having fewer than 25 clumps per hectare (these cannot be classified as bamboo areas).

Table 2. Stock and annual yield of *D. strictus* in three states of India.

| State | Stock | | Annual yield (tonnes/ha) |
|---|---|---|---|
| | No. of clumps/ha | No. of culms/clump | |
| Uttar Pradesh (Kalagarh) | 61.1 | Old 7.29<br>New 2.01 | 0.173 |
| Madhya Pradesh | 121.1 | 27.00 | 1.235 (moist areas)<br>0.618 (dry areas) |
| Maharashtra | 60.9 | 27.02 | 0.568 (N. Kanara)<br>1.952 (Dangs Division) |

Table 3. Yield of *D. strictus* in different locations of three states of India.

| State | No. of culms/tonne Green | Dry | Locality |
|---|---|---|---|
| Uttar Pradesh | 400 | 700 | Kalagarh Division |
| Madhya Pradesh | 310 | - | Umaria Division |
| Maharashtra | 303 | 412 | N. Kanara Division |

In areas where *Bambusa arundinacea* attains robust growth, even 75 clumps per hectare can be classified as dense. In these high-rainfall areas, clumps and culms develop to great sizes and heights.

Table 2 shows that the annual yield of *D. strictus* varies considerably depending upon the intensity of stocking and biotic interference. The number of culms/t also varies in this species from locality to locality (Table 3). The yield of bamboos found in Assam is high. *Bambusa tulda* produces 3.12 t (dry)/ha, whereas *Melocanna baccifera* gives 4.0 t (dry)/ha.

There are two major considerations in the management of bamboo areas — felling cycle and felling intensity. The length of the felling cycle is determined by the minimum age at which the culm is exploitable (which is over age 1 year for *D. strictus*), age of full maturity of the culm (about 3 years for *D. strictus*), and life of the culm (7–8 years for *D. strictus*). The felling cycle for *D. strictus* falls between 2 and 6 years; too short a felling cycle brings about the deterioration of the clump, and a long felling cycle may result in overcrowding. A felling cycle of 3–4 years is, therefore, generally prescribed. Adoption of this felling cycle receives support from field experiments carried out from time to time.

One of the earliest experiments was carried out in Saharanpur Division in Uttar Pradesh (now Siwalik Forest Division) in 1910. The object of the experiment was to determine how different felling methods affected development and production of bamboos (*D. strictus*). Treatments were cutting the culms above the first node, above the third node, and above the fifth node; working on a rotation of 1 year, 2 years, 3 years, and 4 years; and in the first- and second-year rotation clumps, cutting all the culms of more than one rain and half the culms of more than one rain. The results were that cutting above the first node, third node, and fifth node had no effect on the health of clumps; a rotation of 1 year produced switch-like culms and the longer the rotation, the thicker and fewer were the culms; felling all the culms killed the clumps in 2–3 years; and production of new culms was not affected by height of cutting.

Experiments were also conducted between 1934 and 1947 on an all-India basis to determine the best felling cycle, treatment, etc. for *D. strictus*. Regions covered were Madhya Pradesh, Orissa, Punjab, and Uttar Pradesh. These experiments did not indicate a superiority of any one felling cycle, but there was an indication in some plots that a 2-year felling cycle was the least advantageous if the quality of new culms and the number of salable culms were considered. Practical considerations involved in forest working were also against a felling cycle of 2 years. The all-India experiments also indicated that felling all culms other than those produced during that year was not advantageous, because this process resulted in high mortality as well as fewer and poorer-quality new and salable culms.

Detailed statistics regarding the relationship between new culm production and the number of old culms for other bamboo species are not available. Enumerations carried out in Orissa in 1939 suggest average new production as a percentage of old culms for *Bambusa arundinacea* to be 10%; figures from Assam in 1935–36 were for *Dendrocalamus hamiltonii* 38%; for *Gigantochloa* *macrostachya* 38%; for *Neohouzeoua dulloa* 34%; and for *Melocanna baccifera* 35%.

Observations made during 1958–59 over a small number of clumps of *Bambusa tulda* and *Dendrocalamus longispathus* in artificial plantations at FRI indicated average production rates of 18% and 17% respectively. Species in which the percentage of new culms produced is high could probably be worked on a shorter rotation than 4 years.

There are general rules for working bamboo areas, although minor modifications may be necessary in different localities:

- Immature culms younger than 1 year old should not be cut;
- In a clump containing 12 culms or more, at least 6 mature culms over 1 year old should be retained, and in a clump containing fewer than 3 mature culms over 1 year old, all should be retained during the felling;
- The height above the ground at which the culms are cut should not be below the second node and not higher than 30 cm;
- All the debris and cut branches of the culm should be removed completely;
- No fellings should be done from 1 July to 30 September, i.e., during the growing season; and
- Bamboos should not be cut in the year of their flowering; all such clumps should be clear-felled after they have shed their seed.

All the rules are of great importance and are intended to safeguard the bamboo clumps, but applying them is not without problems. The centrifugal manner in which the clump expands leaves most of the younger culms on the periphery enclosing the older ones. Although it is desirable that the older culms be cut and the younger ones on the periphery be retained, it is rather difficult to approach the utilizable bamboos without sacrificing a few young culms. If the clump is congested in nature, the problem becomes more acute. Some improvisations like the horse-shoe method of exploitation are suggested, but on a large scale they are hardly practicable. In fact each clump presents an individual problem and has to be dealt with on its merits. As an extreme case highly congested clumps that do not permit any kind of approach for exploitation may be clear-felled, in anticipation that the new culms arising from the living rhizomes of such clumps may produce better-shaped clumps. Although such a hope is not so far supported by experiments and the matter is open to controversy, practical considerations indicate that clear-felling an extremely congested clump may be preferable to leaving it untouched throughout its life.

## Utilization

Bamboos have age-old connections with the material needs of the common people. Aptly called the "poor man's timber," they are very important to the people of the East, where they are found in greatest abundance and variety. The strength of bamboo culms, their straightness, lightness combined with hardness, range in size, abundance, easy propagation, and the short period in which they attain maturity make them suitable for a variety of purposes, including houses, mats, scaffoldings, ladders, bridges, fences, sticks, tool handles, brushes, pipes, fans, umbrellas, toys, sports goods, musical instruments, spears, bows and arrows, boats and rafts, fishing rods, caps, baskets, flowerpots, furniture, chicks, kites, and, last but not least, paper. In addition, bamboo is a popular ornamental. As a living plant it is used for hedges and in landscape gardening. It is valuable as a windbreak and is particularly useful for preventing soil erosion on account of its interwoven root system. Because of this extraordinary range of uses to which bamboos are put, they have assumed world importance.

Bamboo leaves are used for thatching and are also valued as fodder; elephants in particular are fond of them. Dried and mature bamboo leaves are used for deodorizing fish oils. Bamboo sheaths are used in linings of hats and sandals; they are also used in an artistic way for dried-flower arrangements. Bamboo seeds are extensively eaten by the poor during famine — the times, by accident or design of nature, invariably associated with the gregarious bamboo flowering. The young and tender shoots of certain bamboos (some species are reported to be poisonous), such as *Dendrocalamus giganteus*, are made into pickles and vegetables that are considered to be delicacies. In medicine, too, bamboos have enjoyed a considerable reputation. *Tabashir* or *banslochan*, which is precipitated in the form of amorphous silica in a microscopically fine state within the internodes of many bamboos, is largely used as a cooling tonic and aphrodisiac. Its presence is generally detected by a rattling sound when the bamboo culms are shaken. The rhizome of *D. hamiltonii*, with slight trimming and dressing, is an exact replica of a rhinoceros horn, which fetches a fabulous price as an aphrodisiac. Only an expert can differentiate between the imitation rhino horn and the real; this nefarious use, however, needs to be discouraged.

As a result of modern technological advances, new uses for bamboo and bamboo products have been developed. For instance, *tabashir* has been shown to have excellent properties as a catalyst for certain chemical reactions. Carbonized filaments made from bamboo fibre have been used as light-giving elements in special-purpose electric lamps. The charcoal from bamboos, which is generally used in goldsmithery, has properties that render it superior to that derived from conventional sources for use in electric batteries. Preparation of liquid diesel fuel and isolation of a crystalline compound related to the female sex hormone from bamboos have also been reported. In addition to enzymes that have been extracted from bamboo shoots, an aqueous extract of the shoots has now been found to be superior to conventional media for the culture of certain pathogenic bacteria. The extract, when added to tuberculin, increases the intensity of responses to the skin test.

Bamboos have special significance to the military. During World War II, large quantities of bamboos were used for air-raid covers for buildings and as substitutes for timber in numerous constructions. They have also been used for construction of temporary bridges when permanent bridges were blown away by retreating armies. Recently, bamboo has been used to reinforce cement concrete. In this process bamboos replace steel in the construction of roof slabs, beams, electric posts, etc. The economy achieved is 33% over steel-reinforced constructions.

The bamboo industry in India may be said to be in a primitive state, especially in the handicraft sphere. But India leads the Asian countries in the utilization of bamboo for paper manufacture, which is the most important industrial use of this raw material. It is estimated that, of an annual production of nearly 3.23 million t of air-dried bamboo in India, about 2 million t are being used at present for paper making. This leads to the production of roughly 600 000 t of paper pulp per year. The requirement of bamboo for pulp and paper in this country is, however, higher than what is at present being utilized. It is estimated that this requirement is in the order of 2.2 million t in 1980, and it may go up to 3.1 million t by 1985 and 3.5 million t at the turn of the century. The principal accessible source of paper pulp of acceptable quality in India is the male bamboo, *Dendrocalamus strictus*.

In certain states, bamboo areas have been given on long leases to paper and pulp mills, e.g., Orient Paper Mills, West Coast Paper Mills, Straw Products, Ltd, Andhra Paper Mills, and Seshasayee Paper and Board Mills; elsewhere bamboo areas are loaded with rights and concessions of local villagers who are allowed to cut away bamboos annually from areas earmarked for them for house building, basketry, and other cottage industries. The remaining areas are sold annually by public auction. In such areas only culms older than 1 year are to be felled according to the specified rules. Each clump is to be worked in the form of a horseshoe; the bamboos inside this horseshoe are felled and the clump is allowed to grow outward. The felling in every case is to be over by the end of February.

Bamboo resources in India are plentiful, but they are not being utilized to the maximum. Of nearly 100 native bamboos, only about 10 species are being commercially exploited. These are *Bambusa arundinacea, B. balcoa, B. nutans, B. tulda, Dendrocalamus hamiltonii, D. strictus, Melocanna baccifera, Ochlandra ebracteata, O. scriptoria,* and *O. travancorica.* A few other species are used on a very limited scale, mostly in cottage industries of one kind or another. The bamboo-handicraft industry, therefore, requires to be developed to the fullest extent so that bamboo resources may be put to the best use and to maximum benefit. A strong bamboo industry could go a long way in solving rural unemployment and also in earning good foreign exchange from exports. The present revenue derived from bamboo resources, which is estimated at Rs 66.8 million per annum (U.S. $8.537 million) can be further increased if bamboo industries are started and developed along the right lines.

## Research Activities

Bamboos are specific as far as their properties and uses are concerned. Although taken as a whole, they are versatile, not many of them could be classified as multipurpose and few of them can be specifically used for a single purpose. The question of selection of bamboos for specific needs, therefore, is of paramount importance for their economic exploitation. The whole problem revolves around the proper choice of species, which in turn necessitates authentic identification of bamboos before they can be subjected to experimentation or fed to an industry. Investigations on bamboos in view of their major importance to forestry and forest products are on the program of research work of FRI and are receiving a high priority. These investigations are multidisciplinary in nature and embrace biology, silviculture, and utilization. Taxonomy of bamboos, in other words, their identification, is basic to all other angles of study, as has already been emphasized. This study forms one phase of the program being carried out in the Systematic Botany Branch of the Directorate of Biological Research.

Most bamboos flower only once in their lifetime and die soon after. Flowering usually takes place at intervals of several to many years. This phenomenon poses a special problem in bamboo identification as taxonomic differences in plants are primarily based upon reproductive structures of flowers and fruits, which in bamboos are rarely encountered. If, therefore, one has to depend upon the flowers alone, bamboo identification is only possible just before the plant dies. The problem of bamboo identification, in the absence of flowers, has long confronted plant taxonomists all the world over. Recently, however, a significant breakthrough was made by FRI, Dehra Dun, in field identification of bamboos using characters of their culm sheaths and shoots as the basis. Culm sheaths are close-fitting covers present at every node of the bamboo stem and perform the function of protecting, supporting, and stiffening the internodes of young culms that are actively elongating. They are either glabrous and smooth or covered with tomentum of various kinds, and they vary greatly in shape, size, and texture in different species. They are thus more or less distinctive for each species of bamboo. The term sheath is commonly used in a comprehensive sense to include both the sheath proper and its appendages. The sheath proper is the basal and basic part of the structure. The principal appendages are the blade, the ligule, and the auricles. These appendages may assume different sizes and often are entirely absent — a fact that compounds the problem for taxonomists. Another drawback with the culm sheaths is that the series of sheaths that clothe the successive internodes show a progressive change acropetally in size, shape, substance, and vestiture of both the sheath proper and its appendages. A given culm sheath, therefore, is only characteristic of the position of its origin. It has been observed that only the culm sheaths in the mid-culm range are diagnostic of a given species and that, in the sheaths from the base or tip of the culm, the features typical of the species are somewhat obscured. The progressive change in the form and dimensions of the sheaths, therefore, often makes it difficult to pinpoint the species unless one is sure about the position of the particular node in a culm from which the sheath has been removed for study.

The culm buds or the juvenile shoots of bamboos, on the other hand, which appear annually during the rainy season, are highly remarkable. The organs that form the basis of identification in this case, however, are again the sheaths — the bud sheaths — which are situated close to the root system. Of all kinds of sheaths borne by a bamboo plant, those nearer the rhizome or the root portion vary least from node to node within a given species. In other words, these sheaths borne by the new growing shoots are remarkably uniform in all respects within a given species; yet they vary a great deal in shape, size, and structure in different species, giving the young vegetative buds of different species a distinct appearance. These vegetative buds can, therefore, be conveniently used as a tool to distinguish the various species.

Workable keys for identification of some selected bamboos based on qualitative characters of their culm sheaths and juvenile vegetative buds have been published (28, 334), and preparation of a comprehensive work, an *Identification Guide*, accompanied by coloured illustrations is under way. Recently, work has also been initiated on the parameters for identification of bamboos based on the quantitative characters of their culm sheaths; data on 31 species have so far been recorded and are being analyzed. An artificial key for some species is given in Table 4.

By using Table 4 with a critical eye one can easily identify some of the common species. In many cases, however, the culm sheaths may not be diagnostic of the species or they may have degenerated or withered away. In such cases, external morphology of the young culm shoots is highly useful. Thus, preliminary guidelines for species determination using structure of their juvenile shoots are also given in Table 4.

Whereas the diagnostic characters of shoots can be conveniently and effectively used in the field for quick identification of bamboos, they do have a limiting factor: they can only be applied during the rainy season (July–September) when the new vegetative shoots of bamboos make their appearance as cone-like structures. As the growth in height is very rapid in bamboos, these juvenile shoots soon attain the size of a culm and are no longer suitable for identification.

Table 4. Species, chromosome number, characteristics of the culm sheath, and characters of young shoots of some bamboos found in India.

| Species | Chromosome number: Somatic or diploid (2n) | Chromosome number: Gametic or haploid (n) | Reference | Characteristics of culm sheaths | Diagnostic characters of young shoots |
|---|---|---|---|---|---|
| *Arundinaria racemosa* | 48 | | (178) | | |
| *Bambusa arundinacea* | 72<br>70 | | (77)<br>(311) | Elongated, glabrous; thick, small, narrow; culms erect; blade broadly triangular; branches thorny | Metallic, purplish green; growing apex blunt |
| *B. burmanica* | | | | Fairly large, felted; asymmetric or oblique; at least one auricle situated laterally; culm nodes with one white band on both sides | Yellow stripes on green surface; calcareous bands on both sides of the culm node |
| *B. copelandii* | | | | Very large, glabrous; not conical, ligule serrate; blade narrow, elongated, tapering | Blade and edge of sheath very sharp; copper colour; auricles more or less absent |
| *B. glaucescens (B. multiplex, B. nana)* | 72 | | (77) | Conical, broad-based; blade smaller than sheath | Auricles inconspicuous; blade broad at the base, suddenly tapering upward; slender |
| *B. longispiculata* | | | | Fairly large, felted; asymmetric or oblique; auricles at the top; blade triangular-acuminate, cordate at the base; auricles long, ciliate | Grayish green with dark brown hairs; blades leathery and mucronate |
| *B. nutans* | | | | Fairly large, felted; asymmetric or oblique; auricles at the top; blade, triangular-acute, base continuous with long, ciliate band and auricles | Caterpillar-like auricles; body dark brown, apex green |
| *B. pallida* | | | | Conical, broad-based; blade longer than sheath | Green with brown blades; sheaths almost sticking |
| *B. polymorpha* | 72 | | (77) | Very large, glabrous; much broader than long; auricles present, falcate | Auricles biserrate; lower blade brown; other blades green, cup-shaped |
| *B. tulda* | | | | Fairly large, felted; asymmetric or oblique; auricles, at least one of them situated laterally; culm nodes with a white calcareous band on one side | Yellow stripes on green surface; calcareous band on one side of culm node |
| *B. ventricosa* | | | | | Dark brown, apex green; auricles distinct; internodes pitcher-shaped |

*(continued)*

(*Table 4 continued*)

| Species | Chromosome number: Somatic or diploid (2n) | Gametic or haploid (n) | Reference | Characteristics of culm sheaths | Diagnostic characters of young shoots |
|---|---|---|---|---|---|
| *B. vulgaris* | 72 | | (77) | Fairly large, felted; symmetric, broad; covering a major part of the internode, yellow or green; rounded at the top, blade triangular | Dark brown, apex green; auricles distinct; internodes cylindric (not pitcher-shaped); pure green and pure yellow culms with all intermediary shades, yellow with green stripes most common |
| *Cephalostachyum pergracile* | | | | Fairly large, felted; symmetric, broad; much shorter than the internode, chestnut brown | Chestnut-brown body; blades small, cup-shaped; auricles with long hairs |
| *Chimonobambusa falcata (A. falcata)* | 48 | | (178) | | |
| *C. griffithiana (A. griffithiana)* | 48 | | (178) | | |
| *C. hookeriana (A. hookeriana)* | 48 | | (178) | | |
| *C. jaunsarensis (A. jaunsarensis, A. anceps)* | 48 | | (178) | | |
| *C. khasiana (A. khasiana)* | 48 | | (178) | | |
| *Dendrocalamus brandisi* | 72 + 2B | | (77) | Very large, glabrous; not conical, ligule entire; auricles long, not plaited | Gray with blackish effect; blades very dark brown |
| *D. calostachyus* | | | | Very large, glabrous; not conical, ligule entire; auricles short, plaited | Purplish with a tinge of orange and green (pinkish); blades dark green |
| *D. giganteus* | 72 | | (77) | Very large, glabrous; not conical, ligule serrate; blade broadly triangular | Column very big, glaucous-green, glabrous; auricles absent |
| *D. hamiltonii* | | 35 | (252) | Very large, glabrous; conical, broad; auricles absent | Tomentum perfectly black; auricles present; blade stiff and pointed |
| *D. longispathus* | 72 | | (77) | Elongated, glabrous; papyraceous, very long | |
| *D. membranaceus* | | | | Dome-shaped, felted; blade narrow, elongated, tapering | Sheath light brown, mottled; blade linear |
| *D. strictus* | 72 | | (311, 340) | Dome-shaped, felted; blade triangular, pointed | Brown with very thick, dark brown hairs; apex short; auricles absent; culms glaucous |
| *D. mcclelandii* | | | | Elongated, glabrous; thick, small, and narrow; blade lanceolate-acuminate; culms scrambling | Blades reflexed; climbing bamboo with extremely large leaves |

(*continued*)

(*Table 4 concluded*)

| Species | Chromosome number: Somatic or diploid (2n) | Gametic or haploid (n) | Reference | Characteristics of culm sheaths | Diagnostic characters of young shoots |
|---|---|---|---|---|---|
| *Gigantochloa atter* | | | | | A very fine brown strip along the margin of the sheath; culms green or black |
| *Indocalamus wightianus* (*A. wightiana*) | 48 | | (77, 178) | | |
| *Melocanna baccifera* (*M. bambusoides*) | | | | Fairly large, felted; symmetric, narrow; auricles prominent, blade arising from a concave depression | Ligule horseshoe-shaped; blades flagellate; stems single (nonclump-forming) |
| *Ochlandra scriptoria* (*O. rheedii*) | ca 72 | | (77) | | |
| *O. travancorica* | ca 72 | | (77) | | |
| *Oxytenanthera albociliata* | | | | Fairly large, felted; symmetric, broad; covering a major part of the internode, yellow or green; truncate at the top, blade lanceolate and candle-shaped | Variegated; blades reflexed; apex short, pointed |
| *O. abyssinica* | | | | | Blue-green with cream-yellow blades; apex shortly pointed |
| *O. nigrociliata* | | | | Fairly large, felted; symmetric, broad; covering a major part of the internode, yellow or green; blade conical, ligule narrow | Shining black hairs; apex long, pointed; column conical |
| *Phyllostachys aurea* | 48 | | (77, 178) | | |
| *P. bambusoides* | 48 | | (178) | | |
| *Pseudosasa japonica* (*Arundinaria japonica*) | 48 | 24 | (77, 178) (252) | | |
| *Semiarundinaria pantlingii* (*Arundinaria pantlingii*) | | 24 | (252) | | |
| *Thamnocalamus aristatus* (*Arundinaria aristata*) | 48 | 24 | (178) (252) | | |
| *T. falconeri* (*A. falconeri*) | 48 | | (178) | | |
| *T. spathiflorus* (*A. spathiflora*) | 48 | | (178) | | |
| *Thyrsostachys oliveri* | | | | Fairly large, felted; symmetric, narrow; auricles absent, blade arising from a flat top | Yellow lines on the sheaths; blades linear; lower culm nodes often bearded |

It is clear that bamboo identification, which, in the absence of flowers, has hitherto been considered a difficult task, has now become much simpler. One can now easily choose a bamboo as an edible delicacy without running the risk of having picked a poisonous species, pinpoint suitable bamboos for reinforced concrete or pulp and paper, and identify specific bamboos for other needs. However, one thing must be borne in mind: although it is possible to identify individual species of bamboos once they are thoroughly known, it is not always possible, with the present state of knowledge, to determine the generic affinities and the phylogenetic relationships of unknown or imperfectly known bamboos. One must have flowers for this purpose. Therefore, whereas determination of bamboos based on their vegetative characters, whether qualitative or quantitative in nature, is justified on its merits and may be continued as a short-term measure, the conventional approach to bamboo taxonomy using reproductive structures (flowers and fruits) for discrimination of taxa must always be resorted to. It will be the endeavour of FRI, Dehra Dun, to prepare a complete revision of the *Bambusoideae of India* — the monumental work of Gamble (104) — which is out of date.

Some work has also been done in the Wood Anatomy Branch at FRI on the identification of bamboos based on the structure of epidermal peels of the culms. This method is extremely useful in the identification of felled bamboos in a timber depot or a factory yard. In this connection, an intensive study of the variation in the structure of epidermal features and internodal structure was undertaken on 14 important bamboo species — *Bambusa arundinacea, B. nutans, B. polymorpha, B. tulda, B. vulgaris, Cephalostachyum pergracile, Dendrocalamus hamiltonii, D. longispathus, D. membranaceus, D. strictus, Melocanna baccifera, Oxytenanthera abyssinica, O. nigrociliata,* and *Thyrsostachys oliveri* (107, 314). The study has shown that the size, frequency, distribution, and other characteristics of various epidermal features, including hairs and spines along with internodal structure, are useful in differentiating the species. Generic characters, however, are not well-defined; some species within the same genus show greater differences than do those belonging to other genera. For instance, *B. polymorpha* differs from *B. arundinacea* in the shape of long cells, arrangement of papillae, stomatal structure, nature of the cortex, and structure of the central vascular bundles, whereas *D. strictus* resembles the latter practically in all the anatomical features studied. It is interesting to note that excepting *B. polymorpha*, the two genera *Bambusa* and *Dendrocalamus* have several anatomical features in common, suggesting thereby that they have a close affinity. Anatomical study of bamboos of various age groups has shown that no remarkable changes take place in the overall structural pattern of various tissues after about age 6 months. The process of lignification, however, continues for about 3 years.

The cytology of most Bambusoideae is not well-known, but many bamboos studied so far are tetraploids; *Dendrocalamus* and Asiatic species of *Bambusa* are hexaploids. Diploids have so far been found only among the herbaceous bambusoid grasses. Cytologic information on species occurring in India is rather scanty. Somatic chromosome numbers for some species have been reported by Richharia and Kotwal (340), Parthasarathy (311), Darlington and Wylie (77), and Janaki Ammal (178). Meiotic counts for a few species have been reported by Mehra and Sharma (252). There is thus an urgent need for cytologic work on Indian bamboos.

Among bamboos $x = 12$ is recognized as the basic chromosome number, and species with 48, 54, 70, and 72 as somatic chromosome numbers have been recorded. B chromosomes have also been detected in certain species. Meiotic studies on Indian bamboos need also to be undertaken so that an understanding of seed fertility can be achieved. Such studies should be done gradually as and when the flowering material of different taxa becomes available. The chromosome counts of some Indian bamboos (both wild and cultivated) appear in Table 4.

The Directorate of Biological Research at FRI is responsible for the maintenance and development of the live bamboo collection in the arboretum and its dissemination to various state forest departments to meet the particular needs of the states. The FRI arboretum has the richest species collection of bamboos in India. This nucleus collection of nearly 35 species includes commercially important as well as otherwise interesting species from India and abroad that are being investigated with a multidisciplinary approach, e.g., in the fields of timber, engineering, and pulp and paper technology. Species available in the arboretum at FRI, Dehra Dun, as of early 1980, are indicated in Table 1. In addition to this live collection, the FRI maintains a very rich herbarium collection of bamboos from different parts of the world. This collection serves as an authentic record of bamboo vegetation and includes several type specimens.

The practice of bamboo silviculture, or controlled management of bamboo plantations, has been strongly developed in India. However, the activities have so far been confined to a few species, mainly to *Dendrocalamus strictus*, the commonest Indian bamboo. The reasons that this species has been the focus of silvicultural research are its importance to the economy because of its use by the paper industry and its possession of a property apparently rare among the bamboos: a high degree of drought resistance. The latter reason suggests that this species could become an important source of germ plasm to impart drought resistance to synthetic bamboos through hybridization. The scope and volume of published data on the silviculture and management of *D. strictus* in India set it apart from all other bamboos. Familiarity with the long history of the efforts of forestry research in India toward the economic conquest of this bamboo should provide a useful background for the design of studies on other important species. The principal and continuing leader in silvicultural research on bamboos, which mainly covers cultivation techniques and management practices, has been the Directorate of Forestry Research at FRI although significant work has also been done by some of the state forest departments. Many research papers on bamboo silviculture have emanated from FRI of which particular mention should be made of those by Deogun (80), Krishnaswamy (206), and Seth (364, 366). Several important contributions concerning bamboo silviculture were presented at the IV World Forestry Congress held at Dehra Dun in 1954, and an all-India bamboo study tour and symposium was conducted in December 1963–January 1964, the proceedings and recommendations of which (100) throw considerable light on the subject. Some of the other noteworthy publications on bamboo silviculture are those by Prasad (323), Kadambi (182), Ahmed (5), Seth and Mathauda (365), Mathauda (240), Shyam Sunder (376), and Bhat (45). A good review by Huberman on bamboo silviculture appeared in *Unasylva* in 1959 (169). A seminar on bamboos was recently organized by the Karnataka Forest Department (March 1980), and it provided a good opportunity for exchange of views by the experts.

Grasses are the most useful of all plants, and no growing things on earth have so many and so varied uses as the tree grasses, or bamboos. Porterfield (321) stated: "Bamboo is one of those providential developments in nature which, like the horse, the cow, wheat and cotton, have been indirectly responsible for man's own evolution." Kurz (209) listed 124 uses for bamboos in India, and the list has been updated by subsequent workers, recently by Subba Rao (399) and Bahadur (127, 28). Although some of these lists date back a century or more, the amazing bamboo continues to find new uses, even today — a fact convincingly shown by the recent research on the application of bamboo in paper making, construction, architecture, engineering, and modern handicrafts.

To ensure the proper use of bamboos for construction and for other purposes, the Timber Mechanics Branch of FRI has undertaken work on evaluation of physical and mechanical properties of different species. Methods of tests on bamboos were standardized by Sekhar and Rawat (357) and later adopted as the national standard (170). Limaye (219, 220), Sekhar, and others (353, 354, 355, 358) have evaluated strength properties of different bamboo species of different age, position, and localities. Sekhar and Rawat (356) have studied shrinkage and swelling behaviour of bamboos.

Seasoning behaviour of nine bamboo species, *Bambusa arundinacea, B. nutans, B. polymorpha, B. tulda, Dendrocalamus calostachyus, D. hamiltonii, D. longispathus, D. membranaceus,* and *D. strictus* was tested in the round by the Wood Seasoning Branch (338). The study on seasoning behaviour in air, kiln, and over open fire revealed that bamboos in the round are generally liable to considerable degradation during drying in the form of surface cracking, splitting, collapse, and sometimes even fungal decay and borer attack. Air drying is the most practicable and satisfactory procedure, but care must be taken against too rapid drying in hot and dry winds, which can cause cracking, and too sluggish drying, which causes fungal decay. Air drying is complete within about 3 months in clear weather. Of the nine species, *B. arundinacea, D. hamiltonii, D. membranaceus,* and *D. strictus* dry with relatively little cracking or collapse in mature culms. Immature culms are liable to collapse. The other species suffer cracking, severe collapse and excessive shrinkage in drying. Shrinkage is characteristic of bamboos in the round, and is indicative of collapse in bamboos that are green with up to 30% moisture content. Sharma et al. (367) successfully conducted trials on chemical seasoning of round bamboo for handicraft items without any cracking or splitting. The species used was *D. giganteus*. The anti-shrink chemical polyethylene glycol-1000 in a 50% solution was used for a soaking (diffusion) pretreatment of the walls of green bamboo, after which no cracking occurred in air drying.

All bamboo species except *Guadua angustifolia* have been found to be nondurable. The expected life in the open is between 2 and 3 years in the tropical climate. Because of their excellent strength, bamboos find use in construction in the form of poles, trusses, rafters, and purlins. Solid bamboos are used as tent poles, battens, flag posts, etc. Round bamboos are used for scaffoldings, rowboats, and even floating fenders (in bundle form) for the loading and unloading of ships. However, the low durability makes their use uneconomic and rather wasteful and calls for them to be properly preserved. A lot of work on preservative treatments of bamboos has been done by the Wood Preservation Branch. Results, mostly on *B. polymorpha* and *D. strictus*, have indicated that bamboos are refractory to treatment especially in dry conditions. During drying, the sap precipitates in the cell structure, blocking flow passages and making treatments difficult. The inner and outer membranes of bamboo are hard, becoming still harder on drying; thus they prevent the penetration of preserving chemicals even under pressure (329). Moreover, bamboos are susceptible to cracking even under mild treatment pressures, i.e., 5–7 $kg/cm^2$. Although under higher pressures of 14 and 28 kg/cm², adequate loading of preservatives is possible, about 60% of the round bamboos (*D. strictus*) collapse and crack (391). Using a modified Boucherie process with air pressure of 1–1.5 kg/cm² from an ordinary bicycle pump and diffusion treatments with water-soluble preservatives gives thorough treatment with adequate loadings of preservative (277). A sap-displacement method in which green or split bamboos are partly immersed in water-borne preservatives also is adequate treatment of bamboos by "wick action." The amount of time for successful Boucherie treatment has been found to be dependent on the moisture content, permeability, and length of the bamboos. Usually 8–10 hours are required for such treatment. With this method, a treatment plant can process up to 500 bamboo pieces at a time. The diffusion and sap-displacement methods are a bit slower and may take up to 20 days (391); these methods are better-suited to rural application, as no sophisticated equipment is required. Some fundamental work has been done on the identification of diffusion principles in bamboo structure so that the treatment periods can be reduced (31, 32, 207). Ponding (water storage) of bamboos in stagnant water for a few weeks improves their treatability by both pressure and diffusion (391). Treated bamboos have been used in a number of low-cost experimental structures at the FRI. They have also been tried for reinforcement of mud walls. All these structures are giving satisfactory service with little maintenance. Technical know-how on the preservative treatment of bamboos has also been given to other developing countries. An expert from FRI visited Mexico in 1979 and gave advice on developing preservative-treatment procedures for local Mexican species of bamboos.

Due to its rapid growth, easy availability, and great strength, bamboo was considered worthy for the production of building boards; as a result, investigations were carried out in the Composite Wood Branch, and satisfactory boards were developed (275, 276). The process has since been patented (Indian Patent no. 42228). Bamboo mats are woven from bamboo strips, dried, treated with phenol formaldehyde resin (alcohol-soluble), conditioned, and pressed at 150 °C and 28–35 kg/cm² pressure. The duration of pressing time depends upon the thickness of the final product. The board can be prepared as single or multiple mat board. Veneers, veneer mats, sawdust, shavings, etc. can be used as core material or faces in the production of boards. The boards can also be made in the corrugated form. Stringer-type boards can be made with moulds and mandrels. The bamboo boards offer possibilities for use as light partitions or ceilings or for production of moulded items like attaché cases, suitcases, table tops, chair seats, windmill blades, etc.

Looking toward the need for conservation of steel in the country, the Timber Engineering Branch took on a comprehensive research program on composite construction for testing the feasibility of using bamboo as a reinforcing material in various cement concrete precast as well as cast-in-situ structural components. In the initial stages of research, the bamboo's absorption of water from the mixture of cement concrete resulted in dreadful cracks in the concrete components and discouraged the engineers from using it as reinforcement. However, after persistent efforts by Indian scientists, a suitable and easy-to-apply water-repellent has been found, and it has resulted in safe structures. The process was to dip bamboo (*B. arundinacea*) strips 20 × 9 mm in 80/100 grade hot bitumen and then to apply sand blasting. The experiment showed that bitumen acted as a water-repellent and the sand coating helped increase the bond. After being dried, the bamboo strings were tied into a mesh as is usually done for reinforced concrete. These investigations further showed not only that bamboo can be used as a suitable substitute for steel but that it results in savings in cost to the extent of 33% (238). As a result of these investigations, a number of full-scale demonstration-cum-utility structures were built, including a two-story residential block incorporating a variety of structural components ranging from a sunshade to a grain silo. These have been designed and constructed as a means to observe the behaviour under long-term loading and actual occupation. The results are very encouraging, and more such structures are on the program of research investigations.

Considerable research work has been done by the Cellulose and Paper Branch on determining the pulping and paper-making qualities of bamboos. The Indian paper industry is mainly using *D. strictus* and *B. arundinacea*. Paper mills located in the northern part of the country mainly use the former species, whereas the mills situated in the eastern and southern parts are using both species. Other species used on a limited scale are *B. nutans, B. tulda, D. hamiltonii,* and *M. baccifera*. Bamboo was established as a fibrous raw material in 1909 (332) and is being used as a staple fibrous raw material of the Indian paper industry. At present 2 million t are being used annually, and this intake could be increased if the paper industry were using bamboos available in unexploited areas of the Bastar region and northeastern areas of the country. Suitability of bamboo species has been evaluated for various grades of pulp and paper and for different pulping processes (114, 117, 120, 123, 125, 187). Work has also been carried out on the effect of beating variables on sheet formation and determination of relationships among the chemical nature of lignin and hemicellulose and the fibre characteristics and pulp-sheet properties of various bamboo species (119, 121, 124, 386, 387, 390).

Study of variations in fibre length within a bamboo culm showed that the fibre length in the lower portion was generally greater than at higher levels (313). The influence of variation in fibre dimensions and parenchyma proportion on pulp-sheet properties was also investigated, and it was observed that, although the parenchyma proportion has a negative correlation with the sheet properties, fibre dimensions cannot be used as criteria for classifying different bamboo species for pulp and paper (389). A study of the effect of beating on fibre morphology of bamboo pulp revealed that bamboo fibres do not collapse during beating because of their peculiar cell-wall architecture. Unlike the three-layered secondary walls of most wood fibres, bamboo fibres are polylamellated comprising several alternating layers having different fibrillar orientation. Beating causes a progressive loss of the outer lamellae and results in better pliability of the fibres. The manner of separation of the lamellae depends on the number, thickness, and fibrillar orientation of the fibres. Fibrillation and obliteration of the fibre lumen also help in the development of pulp-sheet properties (327).

Work is in progress on the flow characteristics of dilute fibre suspensions of bamboo species and their relationship with the sheet properties. Some of the results obtained on fibre characteristics, pulping and paper-making qualities of various bamboo species are given in Table 5.

At present, 66% of the pulp used in making paper in India comes from bamboo, and there are 30–35 factories in the country that make paper from bamboo pulp, with an annual production estimated at about 600 000 t. In many respects bamboo offers advantages over wood as a raw material for paper-making. It grows rapidly and is ready for use within a few years; when the culms are harvested, new ones are produced, so that a continuous supply of raw

Table 5. Fibre characteristics, pulp- and paper-making properties of some bamboos.

| Species | Fibre characteristics: Fibre length (mm) | Fibre diameter (μm) | Lumen diameter (μm) | Pulping properties: Alkali used (%) | Screened-pulp yield(%) | Paper-making properties: Breaking length (m) | Burst factor | Tear factor |
|---|---|---|---|---|---|---|---|---|
| *B. arundinacea* | 2.24 | 16.34 | 4.93 | 21 | 51.7 | 6750 | 41.3 | 122.9 |
| *B. nutans* | 2.40 | 15.55 | 3.91 | 20 | 54.5 | 7560 | 42.8 | 166.9 |
| *B. polymorpha* | 2.53 | 16.11 | 4.94 | 20 | 43.4 | 6320 | 51.3 | 218.7 |
| *B. tulda* | 2.10 | 15.43 | 5.57 | 21 | 54.4 | 7460 | 50.0 | 181.2 |
| *B. vulgaris* | 2.02 | 15.06 | 5.52 | 22 | 43.8 | 7260 | 50.9 | 134.9 |
| *C. pergracile* | 2.20 | 16.25 | 4.07 | 20 | 52.8 | 7550 | 47.3 | 149.8 |
| *D. hamiltonii* | 2.40 | 18.98 | 3.40 | 19 | 54.2 | 8320 | 53.3 | 194.7 |
| *D. longispathus* | 2.70 | 15.02 | 3.39 | 20 | 48.4 | 7360 | 52.0 | 164.7 |
| *D. strictus* | 2.45 | 14.51 | 2.88 | 22 | 50.9 | 6470 | 44.7 | 190.4 |
| *M. baccifera* | 2.78 | 15.60 | 3.55 | 25 | 43.8 | 5480 | 40.0 | 210.7 |
| *O. nigrociliata* | 2.43 | 15.96 | 3.81 | 23 | 51.8 | 6730 | 49.0 | 168.0 |
| *T. oliveri* | 2.31 | 15.72 | 3.67 | 22 | 47.0 | 5800 | 48.4 | 164.1 |

material can be anticipated. Further, it has no bark to be removed and its high specific gravity ( ~ 0.6) makes possible 10–20% increase in the effective pulp capacity of the digester. It is estimated that 6–7 times as much cellulosic material can be obtained per hectare from a bamboo forest as can be taken from a coniferous or other broad-leaved forest. Bamboo fibres are longer than those of hardwoods but are shorter than those of most coniferous woods. Length-to-width ratios are higher than those of wood fibres; the bamboo fibres are strong and flexible rather than stiff and brittle — features that are better for most papers, especially high-quality ones like facial tissues, bond papers, and stationery.

## Research Needs and Priorities

In conclusion, it may be mentioned that the future research on bamboos in India will lay emphasis, apart from silvicultural management, on certain hitherto neglected areas such as cytology, embryology, physiology of flowering, variation in seedling progeny, and the use of sophisticated methods of vegetative propagation like tissue- and shoot-culture techniques. Studies on anatomy, fibre characteristics, pulping and paper-making qualities, etc. should be extended to as many different species as possible. Collaborative work among the specialists working on bamboos will be encouraged so that meaningful results are obtained speedily for various species. The work on the taxonomy of bamboos will be pursued on the basis of vegetative characters and extended to many more species; whenever feasible, flowering material will be collected and studied. The live collection of bamboo species will be further enriched by contributions from other parts of the world.

To initiate work on the genetic upgrading of bamboos, which is a virgin field, the FRI has recently submitted a research scheme entitled "Bamboo germplasm collection, conservation both in situ and in gene banks and evaluation of these for use in their genetic improvement" to the Government of India under the VI Five Year Plan, and it is expected that it will be launched very shortly. The scheme envisages establishment of three field stations in the country — one each in the East, North, and South for temperate, subtropical, and tropical species respectively — with headquarters at Dehra Dun, for exploration and collection of bamboo germ plasm representing about 100 species occurring wild in India under different climatic conditions. The species will be grown in gene banks for evaluation and further utilization in research. Genetic improvement of about 10 species that are currently commercially exploited will be given a high priority so that improved planting stocks of these are evolved and used in all future planting work. The information gained should provide an idea of natural variation and should indicate steps for in situ conservation of selected stands in certain areas. The work will include a survey and exploration of major bamboo areas and their study for genetic diversity and selection of suitable clones for conservation; collection of material for taxonomic, cytologic, and palynologic studies; establishment of gene banks with clones from different species in appropriate designs so that they can be evaluated for survival, growth performance, and variation in culm characteristics; selection of variants and inclusion of them in the gene banks; establishment of one-parent progeny trials from seeds of species that may occasionally come into flower, evaluation of the progeny, selection of desirable seedlings, and the cloning of them for use in clonal trials that will also throw light on the breeding system of the species; and exploratory controlled hybridization with commercially important species of *Bambusa* with *B. atra*, a constant-flowering bamboo, species of *Arundinaria* sensu lato with *Indocalamus wightianus*, an annual-flowering species, etc. and study of the interspecific hybrids that may be realized, for desirable characteristics and production of clones for general planting.

In view of the lack of seeds in general and the difficulty often encountered with the transport of bulky offsets for propagation, it may be worthwhile to introduce the techniques of tissue culture and shoot culture in bamboos. These techniques make the exchange and establishment of germ plasm much easier. Research in this direction, therefore, should be given a high priority. Another area that requires to be investigated on a priority basis is the mechanism of flowering in bamboos; to this day the mechanism is one of the greatest botanic mysteries. An understanding of it would facilitate control over flowering of a given species. Induction of flowering at will would facilitate the provision of flowering material to taxonomists for study of the generic affinities of various species and to the breeder for controlled hybridization and other studies like progeny testing. If this feat is achieved in the field of physiology of bamboo flowering, it could go a long way toward serving the cause of science, both applied and fundamental.

# Japan

Summaries of research activities on bamboo in Japan are presented, covering the plant's distribution and morphology, ecology and physiology, cultivation practices, pathology and entomology, anatomy, physical and biophysical properties, chemistry and biochemistry, and uses in pulp and paper making. Some information is also given on research on *Sasa*.

Studies on the distribution and morphology of bamboos in Japan have been recorded since 1900. The forerunner was Makino (230, 231) who was a representative botanist in those days and established the basis of the present taxonomy on bamboos. In 1914, Tsuboi (425), as a bamboo fan or sympathizer, produced and published beautiful and interesting illustrations of typical Japanese bamboos. During the 1930s the bamboo distribution in various districts was actively investigated by Nakai (271) and Koidzumi (201), who discovered numerous new species. After that, Muroi (263–65) made public several new species during the 1950s; at present, the numbers have reached 13 genera, 669 species, 23 varieties, and 16 forms. The discrimination of the species was entirely based on the vegetative parts of the plant, because the flowers are morphologically so much the same among the different species in the same genus, especially in the *Sasa* group. In fact, Takagi (411–12) attempted to distinguish the species in the *Sasa* group by the flowers but was unsuccessful.

It has been recognized (172, 403, 453) that the morphologic characters of vegetative parts in small-sized bamboos have changed to suit their living environment. Usui (453) made clear the variability of morphologic features by publicizing different circumstances where *Sasa*-type undergrowth thrives. Suzuki (403) investigated quantitatively the vegetative parts of the *Sasa* group to discriminate the *Sasa* species. Isa (172) recognized experimentally the variability of vegetative characters in *Sasa* under various artificial environments, and Fujimoto (102) took notice of a great variability in leaves among vegetative parts and tried to make classifications by the form of the leaves.

Asano (22, 23) has proceeded with taxonomic and ecologic observations of the *Sasa* group, and Suzuki (400) dug into the confusion of taxonomy in the 1960s, reexamined Japanese bamboos from both sides of ecology and botany,

*This paper was prepared by a group of scientists — the sections on distribution and morphology, pathology and entomology by M. Watanabe (Experimental Forest Station, Kyoto University); ecology and physiology as well as cultivation practices by T. Suzuki (Kansai Branch, Forestry and Forest Products Research Institute); morphology and anatomy by K. Shimaji (Wood Research Institute, Kyoto University); physical and biophysical properties by T. Nomura (Wood Research Institute, Kyoto University); chemistry and biochemistry by T. Higuchi (Wood Research Institute, Kyoto University); bamboo for pulp and paper by R. Oye (Faculty of Agriculture, Tokyo University of Agriculture and Technology); and* Sasa *by K. Kawase (College Experiment Forest, Hokkaido University) — and was presented by R. Oye.*

and at last accomplished an *Index to Japanese Bambusaceae* in 1978. He has classified Japanese bamboos into 13 genera, 8 sections, 95 species, 7 subspecies, 63 varieties, and 72 forms, totaling 237. His publication has been the most reasonable in this field.

More recently, Murata (261) revised taxonomically a few parts of the *Sasa* group and small-sized bamboos, and then Maruyama (236) proposed a new genus. Still, studies on the taxonomy and morphology of bamboo in Japan are not completed and are proceeding from the standpoints of ecology and fundamental taxonomy.

## Ecology and Physiology

Bamboo forests or groves cover about 123 000 ha in Japan. The main bamboo species are *Phyllostachys reticulata* C. Koch, or *P. bambusoides* Sieb. (*Madake* in Japanese), and *P. edulis* Makino (*Mosochiku*). These two species occupy around 84% of the total.

Hashimoto and Watanabe (143, 145); Numata et al. (287); and Ueda and Numata (442) studied some aspects on structure and increment of bamboo stands in relation to growth type, water economy, and other factors. Aoki (15, 16) and Shigematsu (371) analyzed the culm-growth curve and stand increments of several bamboo species, and Suzuki (405), Uchimura (428), and Watanabe (460) investigated the biomass and productivity of *Madake* and *Mosochiku* stands from the ecologic viewpoint, comparing the features of a bamboo stand with those of a stand of trees.

Ueda et al. (441, 443, 444, 446), Saito (349), Shigematsu (370), and Suzuki (402) studied the preservation and movement of plant nutrients such as starch, protein, mineral elements, and plant-growth hormones in the bamboo.

Although bamboo usually propagates asexually, it flowers only after some years and dies. The flowering and the death of bamboo forests result in a marked shortage of raw bamboo materials for many uses. Since 1960, when the flowering of *Madake* forests and groves occurred on a large scale in Japan, many researchers have been concerned with this problem.

As for the causes or the factors of flowering and death of bamboo, some theories, such as the theory on plant nutrients (265, 435), the theory on life cycle (194, 237), and that on individual strain and mutation (188, 189) have been proposed, but no conclusions have been drawn.

Ueda (433), Numata (286), and Uchimura (430) investigated the ecologic and physiologic aspects of flowering bamboo stands, concerning in particular the process of flowering, withering of standing bamboos, and the natural regenerative recovery from the rhizome. Furthermore, Uchimura (430) and Ueda (434) performed some treatment tests and investigations in the flowering bamboo stands. They observed that the regenerative recovery of flowering bamboo stands is promoted remarkably by treatments such as suitable fertilization and rational selective cutting.

Because the flowering cycle of the monopodial types found in Japan is, in general, very long and because the bamboos do not produce available seeds after flowering, it is difficult to conduct genetic research on the bamboo; however Ueda et al. (447–49) performed some artificial germination tests, physical treatment tests of seeds, and hybridization experiments on several bamboo species. Many of the studies in ecologic and physiologic fields have been summarized by Numata (288) and published in book form by Ueda (437, 438).

## Cultivation and Management Practices

Aoki (13, 14, 19, 21); Suzuki and Narita (406); Ueda et al. (439, 440, 445); and Uchimura (428) have conducted some practical experiments and tests on *Madake* and *Mosochiku* stands to clarify the effects of fertilizing and felling methods. From their experiments, they found that fertilization increases stands, although the amount of increase varies more or less according to the composition of the fertilizer and the season of application. They also observed that the stand structure and increment are improved remarkably if the culms that have reached an appropriate age are cut and a suitable number of good-quality bamboos are left standing.

Aoki (17, 18) prepared tables on volume of stems and growth increments for *Madake* stands in northern Kyushu district. Ogawa and Ando (289) and Uchimura (428) analyzed the relation between the stand density and diameter of culm or other factors for a number of bamboo stands and intended to set up standards.

Besides, Ueda (432) observed the important role of bamboo stands in preventing soil erosion, and Suzuki (404) investigated bamboo forests in Kyoto district from the viewpoint of economic management.

## Pathology and Entomology

The studies on pathology and entomology of bamboo in Japan can be divided into two fields — one is that of living bamboos in forests and the other is that of cut bamboo or harvested bamboo culms and bamboo products. The former is important for the forest protection of bamboo and the latter for the preservation and custody of bamboo culms and products. Studies on both fields have been carried out since the 1930s and Takenouchi (415), the forerunner of general studies on bamboo, outlined them in 1932.

On and after 1950, the studies in these fields picked up with the development of bamboo industries in Japan. Research works on bamboo fungi have been fundamentally done by Hino (162, 163), and informative results were obtained. After that, Hamada (131, 133) proceeded with studies on the protection against fungi attack, and Mikami (254) applied some preservatives experimentally. On the subject of bamboo forest protection, Ueda (437) has reported ecologic habits of insects attacking bamboo forests and how to protect against them.

The studies on protection against mould and insects have been intensified since the 1960s because of the recent emphasis on bamboo products. Hamada (132, 134) recorded the species of insects that attack the culms and their natural enemies; then Okutani (292) recorded 6 orders, 24 families, 44 genera, and 52 species of noxious insects. The most typical insect damaging harvested culms or bamboo products in Japan is *Dinoderus minutus* (12, 132, 254, 467).

There are two ways to protect against insect damage — one is to vary the harvesting season for living culms and the other is to treat the cut bamboos by some physical or chemical means. The worst harvesting season in Japan, that is, when harvested culms may be severely attacked, is April–June (12, 467, 470) for *Phyllostachys bambusoides*. Generally, the best season for harvesting — that is, the time when insect damage can almost be avoided — is late fall (268, 470). Physical treatments for cut bamboos include heating above a flame, boiling in water, coating with chemicals, and bleaching (131). There are various studies on application of chemicals.

In the past, the chemicals containing Dieldrin (132, 413, 466) as a main ingredient were reported to be the most effective for protection against insects. However, recently the dosage of Dieldrin has been decreased because of the residual-insecticide problem. From now on, Chlorden (94) may be applied as an alternative. Organic mercurials (131), tin compounds (131), PCP (131, 193), and sodium boric acid solutions (93) have also been reported as effective against fungi. Studies on protection against insects and fungi have been scholarly (180) and thus have provided impetus for more research.

## Morphology and Anatomy

As most Japanese bamboo species have single culms, descriptions of them include culm length, internode length, internode diameter (or girth), number of internodes, and culm-wall thickness. Studies on these factors from an anatomical or physiologic viewpoint have disclosed that each bamboo species has its own special form of culm (145, 164, 177, 198, 199, 205, 299, 378, 379, 419, 438).

Several studies of the culm tissues have been carried out (146, 177, 197–99, 238, 272, 273, 300, 301, 303, 348, 380, 381, 410, 419, 423, 438, 450, 452); among them, the focus has been on the dimension and the amount of fibres as well as of fibrous tissues (197, 283, 380, 381, 423, 438, 452), and on the distribution (146, 177, 303, 348) and anatomical structure (177, 199, 450) of vascular bundles. The fibre dimensions (380, 381, 438), structure of vascular bundles (177, 197, 198, 380), and their axial and radial variations within a culm have been reported in some species. Correlations between the anatomical characteristics and physical properties of bamboo wood have also been studied (198, 273, 300, 301, 410). Ontogenetic studies on the development and lignification of culm tissues are under way at present (177), and their extension in future is expected.

A couple of comprehensive textbooks with emphasis on bamboo, covering morphology and anatomy, have been published (415, 451), and the morphologic and anatomical studies on the artificial quadrangular bamboo culms are unique in the field (144, 199, 431).

## Physical and Biophysical Properties

The physical and mechanical properties of bamboo were studied by Moniwa (257), Shigematsu (369), Ota (299–302), Kitamura (197), and Suzuki (410). Generally, they found that compact fibre tissues are contained in the outer part of the bamboo culm, whereas the inner part is mostly composed of parenchyma cells. Because of these anatomical features, the specific gravity, bending, tensile, compression, and shear strength are greater in the outer wall. The differences between the inner and outer parts decrease as the height from the ground increases because of the decreasing thickness of the culm wall.

For example, the relation between the bending strength and Young's modulus E of *Moso* bamboo can be expressed experimentally as $144\ E \times 10^{-4}$ ($kg/cm^2$) or $E = 69\ kg/cm^2$ (410). The shrinkage of tangential, radial, and longitudinal dimensions after oven drying of green bamboo is 8.24, 6.84, and 0.17% in the outer culm, and 4.11, 7.21, and 0.43% on the inner wall (410).

The fibre-saturation points determined on the moisture content that effect swelling and shrinkage of bamboo are 17.2 and 16.5% respectively. These values are lower than the value for wood (20–35%) (302).

To elucidate the biophysic properties of plant stems in the growing process, bamboo is the most suitable plant because it grows rapidly, and samples can be collected at each stage of the growing process. *Moso* bamboo (*Phyllostachys pubescens* Mazel ex Houzeau de Lehaie) grows to its full size within about 2 months but takes about 3 years for complete maturation. The main histologic structure, composed of cellulose fibres, is complete at an earlier period, the cell-wall growth and lignification proceeding more gradually.

Crystallinity change of cellulose in the bamboo internode in the growing stage has been investigated (284); an X-ray fibre diagram of bamboo in the growing stage from juvenile to mature showed that the amorphous pattern of cellulose appeared first and then its gradual orientation. The crystalline region was greater in the parts where coleoptile (bamboo sheath) was stripped off than in the parts covered with it; crystallinity decreased rapidly toward the upper parts of the bamboo shoot. In the stage of internodal growth, crystallinity in a given internode decreased from the upper side to the under side of the internode.

## Chemistry and Biochemistry

### Biosynthesis of Lignin

In spring, bamboo shoots come from subterranean stems and grow within a month to full size (10–20 m in height). These are, therefore, suitable plant materials for tissue investigations. They exhibit various phases of lignification from the top to the lower parts of the same individual plant.

Tracer experiments with $^{14}C$-labeled compounds established that lignin is synthesized from glucose via the "shikimate-cinnamate pathway" (Fig. 1). D-glucose-6-phosphate- and 6-phospho-gluconate dehydrogenases (155), 5-dehydroquinate hydro-lyase (156), and 5-dehydroshikimate reductase (154), which are involved in the synthesis of shikimic acid, were isolated from bamboo shoots and characterized. Their activities in various parts of the

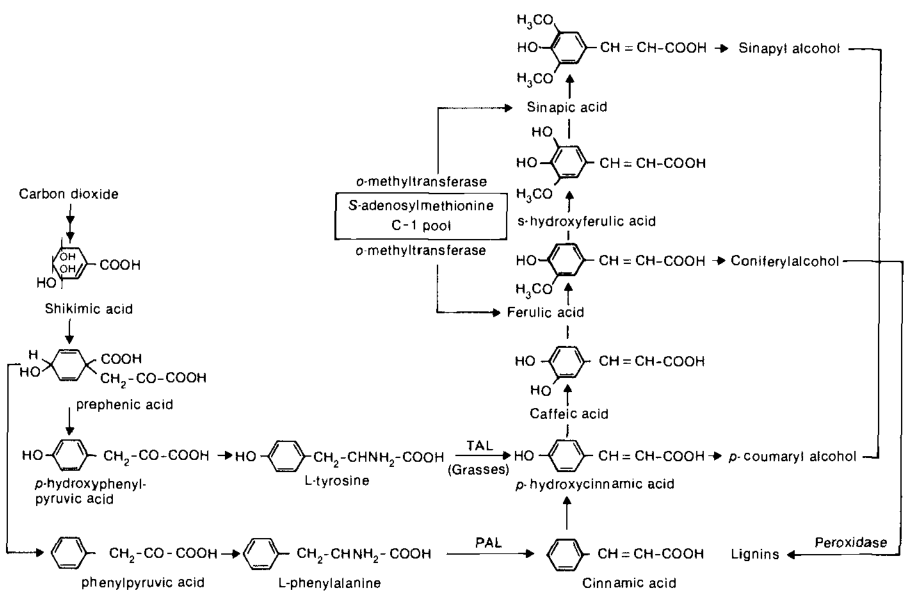



**Fig. 1.** *Metabolic pathway of carbon dioxide to lignin.*

bamboo shoots were determined in relation to lignification of the tissues, and it was found that in the early stages of growth of the bamboo shoots, the enzymes in the shikimate pathway and the aromatic-acid transaminases dominate (157) in the synthesis of phenylalanine and tyrosine incorporated into protein. However, with the onset of lignification, the metabolic system is transformed to accelerate the synthesis of a series of enzymes involved in lignin biosynthesis; the activities of phenylalanine ammonia-lyase, tyrosine ammonia-lyase (150), and cinnamate-4-hydroxylase, which are involved in the synthesis of *p*-hydroxycinnamate, increase dramatically during lignification of bamboo shoots (374).

*O*-methyltransferase involved in the synthesis of ferulic and sinapic acids, percursors of guaiacyl and syringyl lignins, respectively, were also isolated and characterized from bamboo shoots (159, 372, 373). The formation of guaiacyl lignin and not syringyl lignin in gymnosperms was attributed to the absence of ferulate-5-hydroxylase, poor affinity of *O*-methyltransferase toward 5-hydroxyferulate, and the minimum activity of reducing enzymes for sinapic acid (158).

*O*-methyltransferase, cinnamate-CoA ligase, cinnamoyl-CoA reductase, and aromatic alcohol oxidoreductase in bamboo shoots were found to belong to the angiosperm type, which catalyzes the formation of both guaiacyl and syringyl lignins.

**Chemistry of Bamboo Lignin**

Bamboo lignin is a typical grass lignin composed of mixed dehydrogenation polymers of coniferyl, sinapyl, and *p*-coumaryl alcohols (149, 153, 161, 274). Bamboo and grass lignins are also known to contain 5–10% of ester of *p*-coumaric acid as a unique feature (151, 152). On the basis of alkaline hydrolysis and acidolysis experiments with model compounds, about 80% of the *p*-coumarate in bamboo lignin was found to be esterified via the $\gamma$-hydroxyl groups in the lignin side chain; $\alpha$-linked esters of the acid were estimated to be less than 20%. And the investigation of dehydrogenative polymerization (DHP) of coniferyl *p*-coumarate with conifery alcohol by peroxidase and hydrogen peroxide showed that *p*-coumaric acid moiety was incorporated into DHP via $\gamma$-ester linkage as in bamboo lignins (267).

Acidolysis, permanganate oxidation, and spectroscopic analysis of bamboo lignins showed that the amounts of both uncondensed and condensed types of arylglycerol-$\alpha$, $\beta$-diaryl ether groups in bamboo lignin are phenolic $OH/C_6$-$C_3$, 0.24; $\alpha$-*O*-4, 0.07; $\beta$-*O*-4, 0.56; uncondensed type 0.24 (*p*-hydroxyphenyl, 0.02; guaiacyl, 0.11; and syringyl, 0.11); condensed type 0.32; and condensed type (except $\beta$-*O*-4), 0.13 (160).

**Chemistry of Hemicellulose**

A xylan of bamboo, which was obtained as the fraction forming a precipitate on the addition of Fehling solution, was found to comprise more than 90% of the bamboo hemicellulose. The structural studies by means of methylation analysis and periodate oxidation (Smith degradation) of the xylan gave evidence supporting a 1,4-linked linear polymer and attachments of single-unit side chain such as the residues of L-arabinose and 4-*O*-methyl-D-glucuronic acid. It was thus indicated that the bamboo xylan is a 4-*O*-methyl-D-glucurono-arabinoxylan containing the residues of 4-*O*-methyl-D-glucuronic acid, L-arabinose, and D-xylose in a molar ratio of 1.0 : 1.0–1.3 : 24–25, respectively (226).

However, it seems different from an arabino-(4-*O*-methyl-D-glucurono) xylan found in the wood of gymnosperms, with respect to the degree of branching and molecular properties. It was also found that bamboo xylan contains 6–7% of acetyl groups. These results indicate that the bamboo xylan has a unique feature of Gramineae.

In addition, from the water-soluble fraction of bamboo shoots, a xylan (229), which gives no copper complex with Fehling solution, arabinogalactan, and $\alpha$-glucan (284) were isolated. The yield of the arabinogalactan was 0.3–0.4% and was found to be composed of 1,3-linked D-galacto-pyranosyl residues, similar to the arabinogalactan from plant seeds and the sap of sugar maple (227, 228).

## Bamboo for Pulp and Paper

In the 1950s and 1960s, Ono and Tono studied pulping and paper making from Japanese bamboos. They observed bamboo fibres have a lamellar structure of 7–9 layers and suggested a model of the fibre structure, in which fibrillar layers nearly perpendicular to the fibre axis alternate with those nearly parallel to the axis in 7–9 layers (422). The morphologic changes of bamboo-pulp fibres during beating before sheet making were also elucidated (190).

Studies on pulping of bamboo have since been carried out; for example, Kato published some reports (190, 191). Ono and Tono investigated pulping conditions in two-stage cooking and the influences of sulfur in sulfate cooking (293, 294). An integrated, fine-paper mill using bamboo existed in the west part of the mainland but was shut down in the 1960s. However, research for paper making with foreign bamboo species has been continued at laboratories of some pulp and paper companies.

The institute of paper making in Kochi Prefecture is doing research to produce alkaline pulp on a small scale from waste products of bamboo basketry and other uses. When bamboo pulp fibres are blended with other fibres as raw materials for traditional Japanese paper, the quality in such aspects as the gloss from Chinese ink used in brush writing is improved. Recently, an ancient technique to defibrate young bamboo culms using wood ash at ambient temperatures has been studied by Oye, but the findings have not been published. A hand-operated paper maker used by villagers to make Japanese paper actually utilizes this method for bamboo pulp fibres with other fibres.

Another series of research works were those for dissolving a rayon-grade pulp from bamboo. These works were carried out on a foreign bamboo species. Oye et al. (304–08) applied a prehydrolysis sulfate process to *Melocanna baccifera* and produced quality rayon-grade pulp with $\alpha$-cellulose 95.0%, $\beta$-cellulose 4.0%, pentosan 3.0%, extracts 0.03%, ash 0.068%, CaO + MgO 0.024%, brightness 91. They also characterized bamboo rayon-grade pulp compared with wood pulps and pointed out its features. The excess caustic alkali in the alkali cellulose is easier to extract from bamboo pulp than from wood pulp, but the natural bamboo cellulose is rather hard to convert into alkali cellulose. The aging rate or depolymerization rate of the alkali cellulose from bamboo is more than that from wood-pulp cellulose, and the spinnability or tenacity of the gel filament is also superior (Fig. 2). From their results and others, such as the distribution of degree of polymerization, alkali solubility at various concentrations, degree of crystallinity, levelling-off degree of polymerization,

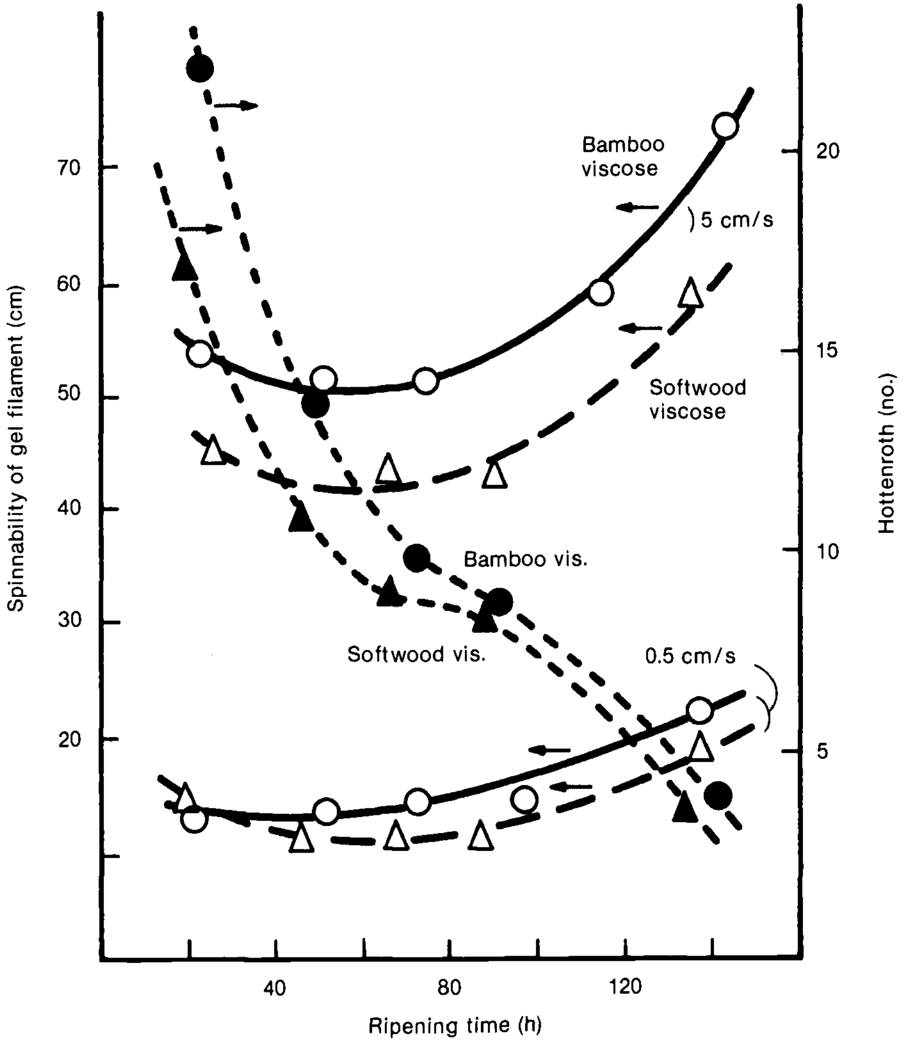



**Fig. 2.** *Spinnability of bamboo viscose at various ripening times.*

and accessibility of bamboo cellulose, the researchers indicated that bamboo cellulose has a fine structure, in which micelle size is homogeneous with smaller amorphous regions distributed evenly (304–08). Recently, it has been shown through X-ray diffraction and other techniques that the mercerization tendency (Fig. 3) of bamboo pulp is dependent upon the fibrillar structure of the fibres.

In alkaline pulping, one of the most difficult problems is in chemical recovery due to the high silica content of bamboo. Elucidating this problem Ono and Isono published some reports on desilicification (173–76, 181), and it has been reported that a pulp company procured patents on desilicification by the addition of calcium oxide to the black liquor and separation by centrifuge (181).

Recently, some unique research has been done on carbonization and graphitization, based on the high crystallinity and high degree of orientation of bamboo cellulose and the structure of bamboo tissues.

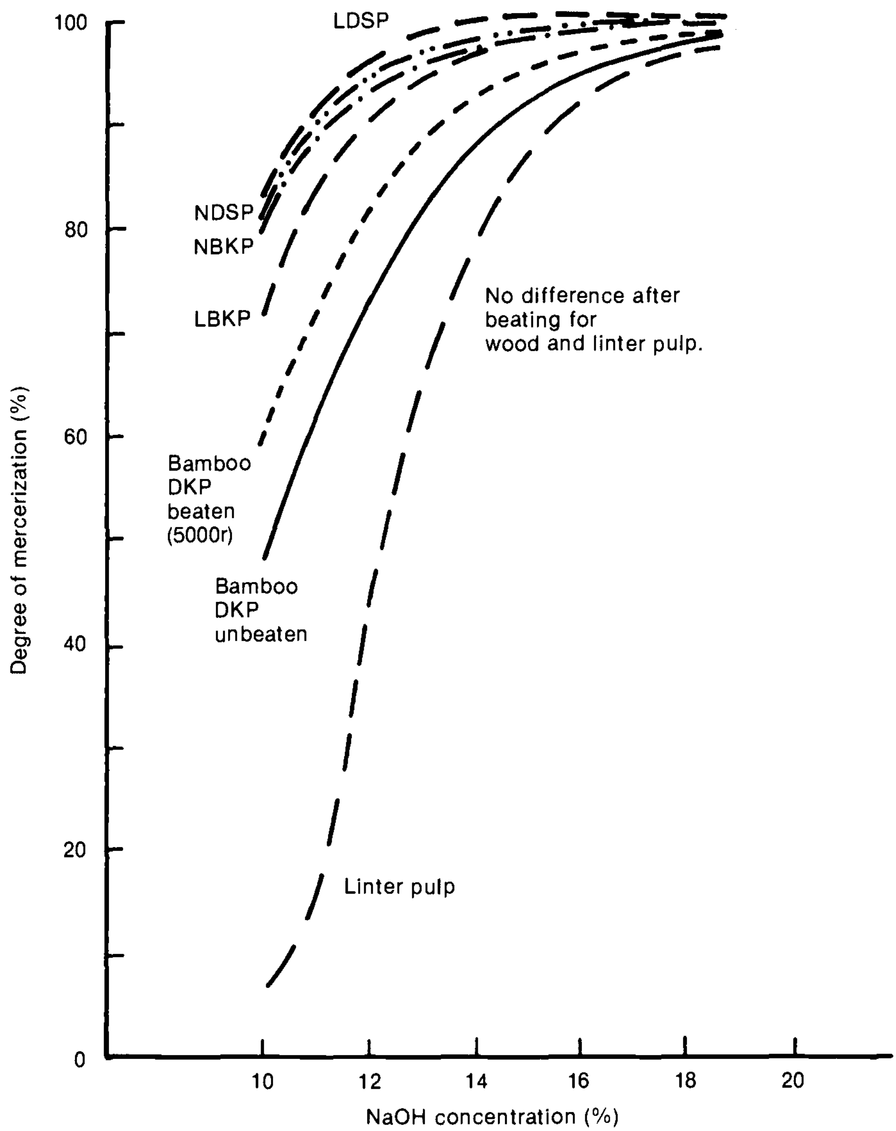



**Fig. 3.** *Degree of mercerization at various NaOH concentrations.*

## Sasa

*Sasa* is a bamboo-like plant growing mainly in Japan and has many species. It is sometimes called bamboo grass or *Sasa* bamboo. It is very difficult to distinguish *Sasa* from bamboo. Generally it is smaller than bamboo, and the culm sheaths are persistent whereas they are deciduous in bamboo (401).

The genus *Sasa* is divided into *Macrochlamys, Sasa* (i.e., *Eusasa*), *Lasioderma, Crassinodi,* and *Monilicladae*. *Macrochlamys* and *Sasa* grow mainly in the northeastern district of Japan. The most important species is *Sasa*

Table 1. Fractionation data (%).

| | Pulp yield | Retention of fibres (mesh) | | | | |
|---|---|---|---|---|---|---|
| | | >24 | 24–42 | 42–80 | 80–150 | 150> |
| *Sasa* | 43 | 28 | 14 | 12 | 5 | 41 |
| *Betula* | 46 | 75 | 15 | 7 | 2 | 1 |
| *Abies* | 48 | 94 | 2 | 2 | 2 | 0 |

*kurilensis* (Ruprecht) Makino et Shibata var. *kurilensis*, a forest resource. *Sasa kurilensis* is abundant in heavy-snowfall districts in Hokkaido and Tohoku and is also found in Hokuriku, San-in, central and southern Saghalien, Kuriles, and northeastern districts of the Korea Peninsula.

*Sasa kurilensis* is the most robust bamboo grass. Its culms are often 3 m or more high and 1–2 cm in diameter; because the culms are crooked at the bottom, this form is called *Nemagaritake* (crooked-root bamboo). The yield of culms harvested for making particle board was observed to be 45 t/ha from the Experiment Forest of Hokkaido University. *Sasa* grows thick in forests, and, although it prevents the erosion of land, it disturbs the regeneration of trees and hinders foresters in their work during the summer. However, *Sasa* species in Hokkaido account for approximately 100 million t of vegetation, which equals one-sixth of the total wood growing in the area. Research work on the industrial utilization of this potentially valuable resource is being carried out.

The chemical composition of the *Sasa* culm is similar to that of hardwood. The specific gravity of the culm is about 0.6 (outer part 0.75 and inner part 0.42). Fibre length is 1.3 mm, as long as that of hardwood, but fractionation of the sulfate pulp is different from that of hardwood (Table 1). The percentage of fine fibres that pass through 150-mesh is higher (41%) than that of birch (1%), and these fibres are almost parenchyma cells. Consequently, in terms of yield the use of *Sasa* pulp is preferable for thick paper and fibreboard than for thin paper.

Commercial production of paper, fibreboard, and particle board from *Sasa* was undertaken some years ago in Hokkaido, but the operation has since been shut down because of the high costs of production — that is, the costs in gathering and bundling the *Sasa* for commercial utilization.

In 1978, about 600 t of *Sasa* shoots were used for food in Japan, and 87 000 bundles of culms were produced for agricultural, horticultural uses, and bamboo works in Hokkaido Prefecture.

Many fundamental studies on utilization of *Sasa* have been done in the last 30 years. Among these studies, works on pulp production (103, 468) are the most numerous. However, recently, the extracts from *Sasa* leaves as a possible cure for cancer have attracted keen interest.

# China

The area of bamboo forests in China is about 2.9 million hectares, 2 million of which are covered by *Phyllostachys pubescens*. There are 26 genera and more than 300 species of bamboos, among which 22 genera and more than 200 species have comparatively high economic value. Bamboo plants are mainly distributed on the plains, hills, and the mountains at altitudes less than 3000 metres in 22 provinces. Research on bamboos in China includes investigations into taxonomic classification, high-yield techniques of cultivation, propagation techniques, disease and pest control, and utilization.

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China has established 23 productive bases of *Phyllostachys pubescens*, from which more than 1 million bamboo culms can be harvested every year. North of Yangtze River, *Phyllostachys pubescens* has been introduced into 230 counties and has become productive forests on Laoshan Mountain in Qingdao area and the northern slope of Qinling Mountains. At the same time, along the Yellow River valley, *P. glauca* and *P. bambusoides*, etc. now cover 30000 hectares — approximately four times the original area of the bamboo forests. In addition, China has had some pleasing results in scientific research on the bamboo resource, biologic characteristics, propagation methods, disease and insect pest control, bamboo wood properties, processing and utilization of bamboos, etc.

## Variety and Distribution of Bamboos

There are 26 genera and more than 300 species of bamboos in China, among which 22 genera and more than 200 species have comparatively high economic value. Bamboo plants are mainly distributed on the plains, hills, and the mountains at altitudes less than 3000 metres in 22 provinces.

The major fascicular bamboo forest regions are south of 25° North latitude. They consist of *Bambusa, Lingnania, Dendrocalamus, Sinocalamus, Schizostachyum, Dinochloa, Pseudostachyum*, and some other genera. In these bamboo forest regions, the southeast coast and Taiwan province are the subregions of southeastern monsoon fascicular bamboo forests where *Sinocalamus latiflorus, B. textilis, B. pervariabilis, B. spinosa*, and *S. oldhami* are the important economic bamboos. The south of Yunnan Province and southeast of Tibet are the subregions of southwestern monsoon fascicular bamboo forests

*Originally written in Chinese by Shi Quantai, this paper was translated into English by Chao Ching-ju, who also presented it. Both Shi and Chao are with the Chinese Academy of Forestry Sciences, Beijing.*

consisting of the major bamboo species such as *Dendrocalamus strictus, S. giganteus, Oxytenanthera fetix*, and so on.

From the Yangtze River to the Nanling is the dispersive, fascicular, and mixed bamboo forest region, which is the largest area among all the bamboo forests. Bamboo is abundant here and is primarily *Bambusa* and *Sinocalamus* of fascicular type, *Pleioblastus* of mixed type, *Phyllostachys* of dispersive type, and some other bamboo species. The Sichuan basin is the most typical mixed bamboo forest region as well as the distribution centre of *Sinocalamus affinis. Phyllostachys pubescens*, which is the most important economically in China, is concentrated (80%) in Zhejiang, Hunan, Jiangxi, and the west of Fujian Province.

From the Yangtze River to the Yellow River is the dispersive bamboo region equivalent to 33–37° North latitude, including the temperate zone of the middle and downstream sections of the Yellow River as well as the temperate zone of Shaanxi, Gansu Province, and Ningxia Hui Autonomous Region where the major bamboo species are *Phyllostachys* of dispersive type and *Pleioblastus* of mixed type. This region contains the major irrigated bamboo forest; irrigation is particularly important before and after the bamboo shoot emerges because of the late rainy season and the insufficient rainfall. On the plains, the major bamboo species are *P. glauca, P. flexuosa, P. nuda*, and *P. bambusoides* f. *tanakae*, etc. In the alpine areas in Shaanxi, Gansu Province, and Ningxia Hui Autonomous Region, there are large *Semiarundinaria nitida* and *Thamnocalamus spathaceus* forests.

## Research on Bamboos

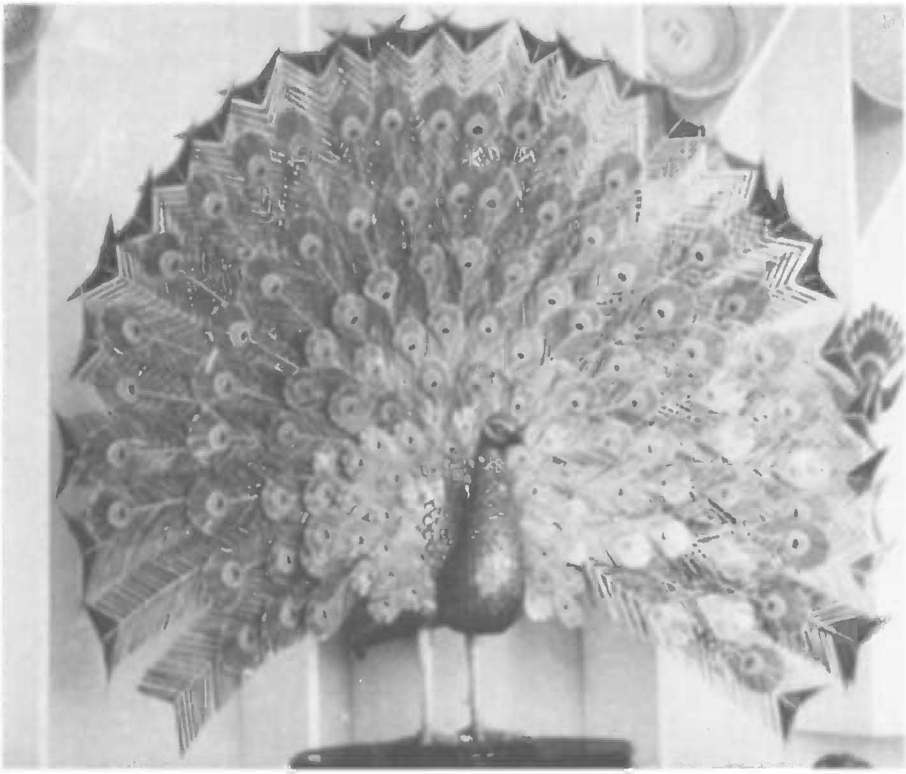
To strengthen the scientific research on bamboos, research departments of bamboos have been established in the Chinese Academy of Forestry Sciences (CAFS) as well as some related colleges of forestry. In some provinces, prefectures, and counties where the major productive areas of *P. pubescens* are located, there are also special research organizations and mass scientific coordination organizations.

### Bamboo Classification

Since the 1970s, the related units of scientific research and teaching, botanical gardens, and forest farms have been organized to carry out research on bamboo classification through which some new bamboo species have been identified and will be publicized.

### High-Yield Techniques

*P. pubescens* is the major timber bamboo species in China. My colleagues and I have researched its biologic properties, the rational structure and nutrient metabolism of high-yield forests, soil moisture and nutrient movement of *P. pubescens* forests, fertilization in bamboo forests, the reasons for the death of bamboo shoots, and the measures for high-yield years and low-yield years. At the same time, we summarized and popularized high-yield measures such as reserving bamboo shoots for the cultivation of bamboos, loosening soil, applying fertilizer, weeding and tending, and rational felling. The effects of such measures are that, now, the circumference of *P. pubescens* at eye level (1.6 m aboveground) is 58.5 cm and it grows 25 m tall. The growing stock of the high-yield *P. pubescens* forests is 225 000 kg; annual output 27 000 kg; the weight of



*A peacock woven from bamboo illustrates the delicacy and art that is incorporated into the skill in China.*

individual *P. glauca* is 25 kg and of *P. bambusoides* f. *tanakae* is 26 kg with a diameter at breast height of 10 cm; the annual output for these two bamboos respectively is 22 000 and 500–30 000 kg per hectare. In addition, the output of fascicular bamboos is much higher than ever before.

**Flowering and Propagation of Bamboos**

We carried out observations on the biologic properties of *P. pubescens, P. viridis, P. purpulata,* "solidstem," and some other flowering bamboos and put forward some renewal measures for different bamboos after flowering. For example, we introduced timely measures for *P. bambusoides* f. *tanakae* in 400 hectares in Bo'ai county, Henan Province, after flowering, and the plants were restored in 3–4 years. We also took measures such as breaking through all the knots in the stumps and pouring urea into the stumps of *P. meyeri* and *P. iridescens* and some other flowering bamboos that enabled the flowering bamboo forests to be restored in 2 years and to reach a productive level before flowering.

In 1962, Huonan Botanical Garden carried out sexual hybridization with flowering bamboos and obtained the hybrid *Bambusa ters* × *B. spinosa*, which grows very well. Since 1972, Guangdong Provincial Research Institute of Forestry has obtained more hybrids; one of them, the 6-year new *Bambusa pervariabilis* × (*Sinocalamus latiflorus* × *Bambusa textilis*) has reached 14 m in height, 8 cm in diameter at breast height and has proved better in mechanical

*Bambusa pervariabilis* × (*Sinocalamus latiflorus* × *Bambusa textilis*).

properties than *Sinocalamus latiflorus*, and nearly as good as *Bambusa pervariabilis*, straight in culm, beautiful in form, useful in architecture, agriculture, and paper making. This is a good beginning for measures to improve bamboo output and quality.

Cultivation of seedlings and afforestation are conducted with the culms of fascicular bamboos and the dormant buds of bamboo branches. The culms, knots, or cutting branches are buried in the soil, and, in recent years, the buried culms and layers of *P. viridis* and *P. glauca* have succeeded in many units in Henan, Shaanxi, and some other provinces.

In addition, research has been carried out on the character, elemental analysis, germination percentage, seedling cultivation techniques, tillering, propagation methods, and afforestation of *P. pubescens*. Many seedlings of vegetative propagation have been cultivated through layering, tillering, and cuttings. In fact, the seedlings of vegetative propagation have generally been used in the whole country in the afforestation of 70 000 hectares in which some have become productive already.

### Disease and Insect Pest Control

According to a preliminary survey, there are more than 100 species of insect pests in China that are harmful to bamboos. Research on the biologic properties and control methods of some major harmful pests such as *Ceracris kiangsu* Tsai, *Algedonia coclesalis* Walker, *Pegomyia kiangsuensis* Fan, *Atrachea vulgaris* Butter, *Otidognathus davidis* Faimdirae, and *Dinoderus minutus* Fabricius have been carried out, and effective control measures have been introduced for *Ceracris kiangsu* Tsai in large areas. At the same time, practical control methods against *Atrachea vulgaris* Butter have also been obtained. After 1975, in Zhejiang Province, *Algedonia coclesalis* Walker damaged more than 700 000 hectares in which more than 4 million stocks of *P. pubescens* died. We introduced control methods such as aerial spraying with insecticides, injections of insecticides into the cavity at the bottom of the plants, and these measures decreased the infested area.

At the beginning of the 1960s, stag-headed disease of *P. pubescens* infected the coastal areas of Zhejiang Province and damaged more than 700 000 hectares of *P. pubescens*; about 5 million stocks of *P. pubescens* died of this disease. Through the coordinated research by the CAFS and Zhejiang Province, we now have a clear understanding of the pathogenesis of the disease, and through preliminary research, we have obtained a whole set of approaches for prognosis and control. Moreover, some research on bamboo-culm rot disease and rust disease has also been carried out.

### Wood Properties and Utilization

Some research has been carried out with *P. pubescens, Sinocalamus affinis, Bambusa textilis*, and some other major bamboo species on the inner wood anatomy and structure, fibre content, physical and chemical properties, and the manufacture of bamboo plywood, acetate fibre, nitrifying fibre, paper, etc. Some of the results have been applied to production, and some have produced data for the classification and identification of the bamboos excavated from the remains of primitive societies (7000 years ago).

## Some Ideas about Bamboo Research in China

The bamboo plants in China are distributed in a broad area where they are an extremely important resource, especially in Tibet (Xizang), Yunnan, Guangxi, etc. Still, the bamboo flora needs to be better exploited and utilized. The present relationship between genera and species of bamboo plants is confusing and needs to be investigated from the viewpoints of the evolutional characteristics of the systematic development and individual development, genetic structure, physiologic mechanisms, biochemic analysis, and comparative anatomy of the bamboos. In other words, we need to find out the parental relationship of bamboo plants and decide the orders and positions of their genera and species.

We also need to research the flowering mechanisms to grasp the techniques promoting or inhibiting flowering so that we may renew the bamboo forests and better understand sexual hybridization.

To control the quantity and quality of bamboo shoots and to raise the economic output and the value of commercial products from bamboo forests, researchers also need to study differentiation of shoot buds and their growth and development.

Furthermore, research should be carried out on the composition and structure of the ecosystem; utilization of energy; the formation of biologic and economic yield; distribution, transportation, storage, and cost of material energy so that the highest-yield stand structure can be introduced. At the same time, comprehensive control of diseases and insect pests with biologic control methods should be actively investigated.

Finally, further study should be carried out on the physical and chemical properties of the various parts of the bamboo plant so that bamboo can be used more fully.

# Indonesia

Although bamboo is used daily by many Indonesians to make items they need, it is not cultivated by the people and has been virtually ignored by researchers. Because of the lack of ample collections of herbarium specimens of bamboo, data on the plant's distribution in Indonesia are lacking and need to be compiled, especially as the uses of bamboo have been extended remarkably in the last few years. The demand for bamboo in industry is very large as well. Notwithstanding these facts, forestry personnel often turn the bamboo grove into *Agathis* or pine plantations. Many objects made of bamboo have already changed to modern technology; therefore the study of bamboo ethnobotany should be encouraged.

The role of bamboos in the daily life of many Indonesians is manifest. Nevertheless, our knowledge of this group of plants is inadequate, and the development of this important resource is handicapped considerably.

## Status of Bamboo Research Activities in Indonesia

Although, economically, bamboo is very important in certain areas, it does not receive enough attention from the government. At present, bamboo is classified as a minor product in forestry. Therefore it is not surprising that in Indonesia research activities on bamboo have been limited and sporadic. The intensified exploitation of bamboos in recent years has been based on traditional technology developed from experience rather than modern research. All research activities performed so far represent sidelines because Indonesia does not have a full-fledged expert on the biology or technology of bamboos.

At the Lembaga Biologi Nasional (the National Biologic Institute), Bogor, research on the ethnobotany of bamboos was initiated in 1975. Musical instruments, wicker items, especially those for carrying things, and fishing equipment are artifacts being studied. The derivation of bamboo and other plant names in Java, the folk taxonomy, and the role of bamboos in many traditional customs are other ethnobotanic topics being investigated. Under the supervision of staff members of the Lembaga Biologi Nasional, several research students from the School of Garden Architecture (University of Trisakti, Jakarta) are now evaluating the increasing utilization of introduced or native bamboo species in landscaping. In cooperation with the Estate Crop Research Institute, some experiments have been conducted on the use of bamboo as the harvesting pole of oil palms; they led to the conclusion that *Melocanna baccifera* was the most suitable species for this purpose. The result has been a plan to plant this species in large quantities in oil-palm areas in Sumatra.

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Although taxonomic study comes naturally under the aegis of Herbarium Bogoriense of the Lembaga Biologi Nasional, the lack of qualified personnel prevents the institute from undertaking research along this line at the moment. Nevertheless, some studies on the use of leaf anatomy in distinguishing species of *Schizostachyum* and *Gigantochloa* have been completed. A serious obstacle to those wishing to do sound taxonomic research is the inadequacy of existing collections. Bamboos have been neglected or avoided by collectors in the past, and collections that have found their way into herbaria are generally poor. The situation is such that it is impossible at the moment to give an accurate picture of bamboo distribution and diversity in Sumatra, for example, based on collections preserved in Herbarium Bogoriense.

Several aspects of bamboo technology have been investigated by the Lembaga Penelitian Hasil Hutan (the Forest Product Research Institute) at Bogor. The strength and the suitability of local bamboos for pulp (183, 184) and the resistance of bamboos against insect infestations were some of the subjects researched there. In conjunction with the Lembaga Penelitian Hutan (the Forestry Research Institute) and the paper factory in South Sulawesi, methods of harvesting were studied. The Lembaga Penelitian Hutan is particularly interested in silvicultural practices of bamboo plantation.

Another institute doing research on bamboo technology is the Lembaga Penelitian Masalah Bangunan (the Building Research Institute) in Bandung. This institute is working on the kinds and the strength of bamboos used for housing and other construction purposes (98). Research on the traditional architecture using bamboo capable of withstanding strong earthquakes is also being pursued, because houses in many areas along the southwest coast of Java have been destroyed by disasters of this kind.

Although it does not have a special research program on bamboo, the Balai Penelitian Kimia (the Chemical Research Institute) in Ujung Pandang now and again undertakes such research. Its main purpose is to find a chemical method of protecting bamboo used in handicrafts against insect attack (38). This type of research is being performed at the request of other institutes or agencies or sometimes private firms that import chemicals.

Also, research students in Indonesian universities occasionally choose bamboo as the subject for their theses. For example, a graduate student from the Akademi Seni Rupa (the College of Fine Arts) in Jakarta was studying the kinds of bamboos used in handicrafts, and a student from the National University at Jakarta was working on the biology of bamboo used in modern construction.

## Current Knowledge of Bamboo Diversity and Distribution

The lack of ample collections of herbarium specimens makes it difficult to present a sound taxonomic judgment on bamboo in Indonesia. In the much used and modern treatise of Javanese flora, Backer (25) enumerated 31 species, but further critical studies (323, 463) revealed that a higher number is likely. There are knotty problems in the *Gigantochloa verticillata-atter-maxima* complex, as well as in the *Schizostachyum biflorum-blumei-longispiculatum* group. Recent collections from the Lesser Sundra Islands yielded many interesting new species (83, 397), and there is no doubt that further novelties will turn up if there are good collectors and good taxonomists around.

For Indonesia, a bold estimate is probably 65 species. This figure — covering both native and introduced species, as well as those cultivated or growing wild in nature — is based on the existing collections preserved in the

Herbarium Bogoriense and on personal observations from field work in Indonesia. Many introduced species are found in Java, planted either for their ornamental value or for their high economic utilization.

Because of uncertainty on the specific status of the bamboos, data on their distribution are also lacking. Similarly, it is not very easy to accumulate data on the size of areas in Indonesia covered by bamboo forests, plantations, or groves. Therefore the estimates given by the Forestry Services concern only certain provinces. In Gowa district there are 15 000 hectares of bamboo forest joined with another 10000-hectare forest in Maros district. This 25000 hectares of bamboo forest is the base of the paper factory in South Celebes. In East Java it is estimated that the bamboo groves occupy some 30 000 hectares.

For almost every genus occurring in Indonesia, a thorough taxonomic revision will be required, especially for genera that have little economic value such as the climbing bamboos.

## Utilization

In many areas of Indonesia, bamboos are a cheap and plentiful resource for the vast and varied needs of the people (Table 1). They have age-old connections with housing, fishing, weaponry, musical instruments, medicine, and landscaping. Therefore, it is not surprising that many species of bamboos are cultivated as "domestic" plants. In fact, the natural distribution of bamboos in Indonesia has been greatly modified by human intervention.

Probably the most important use of bamboos for the majority of Indonesians is in construction. A whole house can be constructed solely from bamboos including its pillars, walls, floors, rafters, and roof (98, 396). Traditional houses in Tana Toraja in Central Celebes, for example, use split bamboos for their roofs. Even in modern and storied buildings, one may still observe bamboos being used for scaffolding. There are also many small bridges in Indonesia that are entirely made of bamboos. Smokehouses for tobacco, *dangau* or guard houses in *sawahs* and *ladangs*, hothouses for growing *padi* straw mushrooms, *lath* houses for the protection of beds and nurseries, all use bamboo as their main component of construction.

Not only are the houses made of bamboos but also the furniture within them. One commonly sees bamboo *balai-balai* (a kind of divan or bed), bamboo *para* (shelves for cupboards, racks, or tables), bamboo stools, or chairs in Indonesian homes.

The Indonesians combine the physical utilization of bamboo with their artistic ability. Therefore, split bamboos are woven into fences, walls, mats, boxes, baskets, or other containers of various sizes and intricate shapes. The methods used are numerous, and the design involves many kinds of patterns normally characteristic for each tribe. Each of the designs or patterns has its own particular meaning and often is used only for a particular purpose. The use of bamboo as raw material for handicrafts should be viewed in this context as well. Toys, flower vases, fans, mats, carvings, paintings, and a thousand other bric-a-brac are artistically prepared from bamboos. *Tangerang* hats have become world famous. The use of bamboo as a source of a much-used string is notable. especially in West Java. For this purpose *Gigantochloa apus* is employed.

It is believed that the fishing industry prompted people to grow plants they required as fishing tools. Bamboo cultivation — like banana cultivation — might have been initiated by fishing activities. In Indonesia much fishing equipment is prepared from bamboo, from simple fishing poles to tools as

Table 1. Species of bamboos and their uses in Indonesia.

| Species | Building material | Smokehouses for tobacco | Baskets | Furniture | Handicraft | Fishing tool | Firewood | Water pipe | Traditional customs | Edible shoot | Musical instrument | Paper industry | Medicine | Ornamental plant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Arundinaria japonica* | | | | | | | ● | | | ● | | | | ● |
| *Bambusa arundinacea* | ● | | | | | | ● | | | ● | | ● | | |
| *B. atra* | ● | | ● | | | | ● | | | | | | | ● |
| *B. blumeana* | ● | | ● | | | ● | ● | | | ● | | | | |
| *B. glaucescens* | | | | | ● | | ● | | | | | | | ● |
| *B. polymorpha* | ● | | | | | | ● | | | ● | | | | |
| *B. vulgaris* | ● | | | ● | ● | | ● | | | ● | | | ● | ● |
| *Dendrocalamus asper* | ● | | ● | ● | ● | ● | ● | ● | | ● | ● | | | |
| *Dinochloa scandens* | | | | | ● | | ● | | | | | | | |
| *Gigantochloa apus* | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ● | | | |
| *G. atter* | ● | | ● | ● | ● | ● | ● | ● | | ● | ● | | | |
| *G.* aff. *atter* | ● | | ● | ● | ● | | ● | ● | | ● | ● | | | |
| *G. verticillata* | ● | | ● | ● | ● | | ● | ● | | ● | ● | | | |
| *Nastus elegantissimus* | ● | ● | | | | | | | | | | | | |
| *Phyllostachys aurea* | | | | | ● | | | | | | | | | ● |
| *P. nigra* | | | | | | | | | | | | | | ● |
| *Schizostachyum blumei* | ● | ● | | | ● | ● | ● | | | ● | ● | | | |
| *S. brachycladum* | ● | ● | ● | ● | ● | ● | ● | | | ● | ● | | | |
| *S. caudatum* | ● | | | | | | | | ● | | | | | |
| *S. lima* | ● | | | | ● | ● | ● | | | ● | ● | | | |
| *S. zollingeri* | ● | | ● | ● | ● | ● | ● | ● | | ● | | | | |
| *Thyrsostachys siamensis* | | | | | | | ● | | | | | | | |

complicated as fish containers with their many unusual shapes. Bamboos also play a role in providing food, because rakes, plows, and other agricultural tools have been made from them. In remote areas where cooking is being done on open fires, bamboo branches represent a cheap firewood (especially in areas like Madura where wood is a scarce commodity). It has been observed also that in Kuningan and in other areas in West Java, bamboos have been used as pipeline to bring water from distant places; in areas with a more intractable topography, bamboo culms are being used as containers in which villagers carry water for drinking purposes. Recently, a technologically minded villager created a water pump made of bamboo and wood capable of pumping water from a well 8 metres deep.

During the war of independence in Indonesia, the lack of weaponry made the Indonesians turn to bamboos again. *Bambu runcing* (a sharpened bamboo spear) is a well-known weapon that has had a respectable place in modern Indonesian history. In the past, bamboo had been much used in weaponry, and, in several kinds of West New Guinean arrows, bamboos are still used.

Bamboos have also played an important role in Indonesian traditions. For instance, in the severance of the umbilical cord of newborns as well as in the circumcision ceremony of a male child, the sharp edge of a freshly split bamboo or *sembilu* was used as a knife, because the people believed that steel knives might cause infection. These kinds of ceremonies often become big festivals for the families with *wayang* (shadow plays) and *gamelan* (traditional music). In many areas bamboo is used in musical instruments such as in Sunda, Talaud, Toraja, and so on (463).

Based on the presence of large tracts of land overgrown by bamboo in Gowa and Maros districts in South Celebes, the government installed a paper factory, and a similar factory was erected in East Java, but the bamboo source turned out to be inadequate for continuous running of the second mill. Now, other pulp sources are being used, among them *Sesbania grandiflora* and rice straw.

Several species of bamboos in Indonesia produce edible shoots, and these are prepared in various kinds of dishes and consumed. Thus, living bamboos prove useful to Indonesians and have recently become part of the landscape of many modern houses.

## Problems Related to Development of Bamboo Resources

The traditional bamboo musical instruments of West Java depend mainly on one species, *Gigantochloa atter* or *bambu hitam*. Not only that, the producers of these instruments insist on the *bambu hitam* from the West Java area. The *bambu hitam* from Central and East Java have larger diameters and, hence, produce differences in the musical instruments. Because of this, musical instruments prepared from bamboo grown in Central or East Java are inferior in quality and, consequently, fetch a lower price.

In recent years there has been a new trend in the use of *bambu hitam*. More and more people have become interested in buying household furniture and handicrafts newly developed from *bambu hitam* in West Java. Therefore, there is competition for the raw materials. The competition is considered unfair because the furniture and handicraft industries normally have enormous capital compared with that available to musical-instrument makers who base their operation on a home-industry scale. In the long run, this trend will be detrimental to the perpetuation of the West Javanese culture.

This problem is mainly due to the fact that people do not grow the bamboo, and the demand for material to be used in the furniture industry is generally large — one set of four chairs and one table will use the same amount of *bambu hitam* as one full orchestra. There is a continuous depletion of *bambu hitam* from West Java because its regeneration is left to nature. In certain areas in West Java (such as in Kuningan district), *bambu hitam* has even been used for water pipes and firewood.

There is no doubt that a way out of this situation is essential. Furniture and handicraft industries should be encouraged to use *bambu hitam* from Central and East Java as well as other species. In fact, the possibility and the suitability of the many other species, for the handicraft industry especially, should be investigated, and the areas capable of serving as a source of raw material should be identified. West Javanese *bambu hitam* should be reserved for the use of West Javanese musical instruments, if the well-known and melodious West Javanese music is to be preserved.

It has been reported that the export of bamboos and bamboo products shows a tendency to decline largely because the harvesting methods are not well managed. For instance, it has been observed that the time of harvest is not correct, and the bamboos are being felled when they are too young to produce good-quality material. It has also been observed that the handicraft industry is forced to utilize this inferior material, so that in the long run the demand for handicrafts will decline.

Another setback is that the forestry industry often turns bamboo groves into *Agathis* or pine plantations. Consequently, regeneration of bamboo groves or bamboo plantation is very rarely undertaken.

## Conclusions and Recommendations

Because existing bamboo collections are inadequate, bamboo exploration should be undertaken and ample herbarium specimens made so that sound taxonomic research can be achieved.

The advancement of modern technology has increased the many artifacts made of bamboos; therefore, the study of bamboo ethnobotany should be encouraged. The well-established use of certain bamboos for artifacts with a long cultural history (such as the use of *bambu hitam* for West Javanese musical instruments) should be preserved.

# Philippines

About 54 species of bamboo have been recorded in the Philippines including the introduced species under the following genera: *Bambusa, Cephalostachyum, Dendrocalamus, Dinochloa, Gigantochloa, Schizostachyum. Thyrsostachys, Leleba, Phyllostachys,* and *Yushania.* Only 8 of the 36 erect bamboos are considered commercially important namely: *Bambusa blumeana, B. vulgaris, Dendrocalamus merrillianus, D. latiflorus, Schizostachyum lumampao, S. lima, Gigantochloa aspera,* and *G. levis.* The Bureau of Forest Development has claimed that as of 1978 there were only 7924 hectares planted with bamboo, and the density of stocking of these areas is not known.

Factors affecting growth and distribution of bamboos in the Philippines include latitude, altitude, temperature, rainfall, and soil quality. Bamboos in the Philippines have been propagated by means of seeds, cuttings, marcotting, ground layering, and offsets. Sexual propagation has been conducted with *Bonkawe, Schizostachyum lumampao, Bambusa arundinacea,* and *Phyllostachys edulis.* Propagation of *Bambusa blumeana, B. vulgaris, Gigantochloa levis, G. aspera,* and *Dendrocalamus merrillianus* by culm cuttings has been successful to various degrees. *Schizostachyum lumampao* and *S. lima* cannot be easily propagated by cuttings but can be successfully propagated by offset planting. *Bambusa blumeana* has also been propagated by marcotting and ground layering with 69.90% and 27.70% survival respectively.

There are no rules that regulate the cutting of bamboos, unlike timber harvesting where specific line-marking rules are implemented by trained line markers. Felling of bamboos has not yet been improved as evidenced by some faulty practices.

The overall research efforts on bamboo in the Philippines are not well known. In 1930, however, one report dealt with the bending and compression strength of one bamboo species; the report was practical and was geared toward applications. This was followed by an anatomical study in 1931, but it was only in 1957, a little more than 2 decades later, when some studies were introduced, and interest in bamboo research was revived.

Albeit substantial technical information has been generated on bamboo, there still exist many gaps both in the production and utilization aspects; to wit, there is a dearth of information on the total area of the natural and artificial stands of bamboos, distribution and density of the different species, yearly production on a per-hectare basis, and current and future requirements of all bamboo-based industries.

*Two representatives of the Philippines attended the workshop and presented their papers; the text of this paper was primarily prepared by Adelaida A. Bumarlong of the Forest Research Institute, College, Laguna, with introductory sections and portions of the research needs, problems, and recommendations by Francisco N. Tamolang of the Forest Products Research and Industries Development Commission also at College, Laguna.*

Also, the information on the taxonomy and phenologic patterns of the different species is very meagre. Even research on propagation and fertilization has been limited to very few species, and the determination of yield and regulations on felling should be intensified and extended to the lesser-known bamboo species. Information on the biologic problems in both natural and artificial stands is wanting, and no investigation on species and varietal improvement has yet been conducted.

Studies aimed toward expanding the uses of bamboo and developing new products that would likely upgrade their commercial value to a considerable degree should be undertaken.

So far, technical data generated on utilization have been confined to a few species. Development of new products from the common species must be intensified, and the lesser-known species should be studied intensively and their potential as substitutes for the common species investigated.

Likewise, research studies on the structural, physical, and mechanical properties need to be expanded to lesser-known species. The data gathered in these studies would serve as a guide on the proper utilization of the species. The pulping qualities of the different bamboo species should also be intensively studied. So far, only 8 of the 55 known species have been studied.

Bamboos, like wood, contain extractives. These should be chemically analyzed for medicinal purposes. The leaves and sheaths are also potential sources of active biologic constituents. Whereas much information has been generated on preservation of bamboos, there is scant information on their service life under field conditions. A simple preservation process against biodeterioration aimed at prolonging the service life of the finished materials such as furniture, bamboo crafts, bamboo parquets, and the like needs special attention. Another aspect worthy of investigation is the seasoning characteristics of some bamboo species, especially in the round form now used in furniture manufacture.

The lack of substantial research data on bamboo utilization points to the need for well-coordinated research studies of the various disciplines involved. Among the problems identified in the bamboo-based industry are insufficient information on the raw material resource base, inadequate knowledge of proper processing techniques, poor marketing strategies, and poor quality control.

The research community itself has problems, some of which include poor links with users of the research output; pressing duties in other fields; inadequate incentives; and communication gaps among researchers.

## Bamboo Production Research

About 55 species of bamboo have been recorded in the Philippines including introduced species under the following genera (427): *Yushania, Bambusa, Dendrocalamus, Gigantochloa, Schizostachyum, Thyrsostachys, Leleba, Phyllostachys, Cephalostachyum,* and *Dinochloa* (Table 1). Some 36 species are erect, and the rest are climbing. At present, the climbing varieties of Philippine bamboos are not locally utilized for the manufacture of worthwhile articles, and not all of the erect species are considered commercially important. Only eight species are widely used for construction purposes and for the manufacture of handicrafts and furniture (57, 224, 297, 331, 408).

*Bambusa blumeana* Schultes f. has the most extensive distribution

Table 1. Bamboos found in the Philippines and some common names.

| Erect bamboos | | Climbing bamboos | |
|---|---|---|---|
| Scientific name | Common name | Scientific name | Common name |
| – | *Bonkawe* | *Cephalostachyum mindorense* Gamble | – |
| *Yushania niitakayamensis* (Hayata) Keng f. | – | *Dinochloa aguilarii* Gamble | – |
| *Bambusa arundinacea* Willd. | India bamboo | *D. ciliata* Kurz | – |
| *B. floribunda* Nakai | – | *E. elmeri* Gamble | – |
| *B. blumeana* Schultes f. | *Kauayan-tinik* | *D. luconiae* (Munro) Merr. | – |
| *B. cornuta* Munro | *Lopa* | *D. pubiramea* (Merr.) Gamble | – |
| *B. merrillii* Gamble | Merrill bamboo | *D. scandens* O. Kuntze | – |
| *B. nana* Roxb. | – | *D. scandens* var. *angustifolia* Hackel ex. Merr. | – |
| *B. tulda* Roxb. | Spineless India bamboo | *Schizostachyum acutiflorum* Munro | – |
| *B. vulgaris* Schrad. ex Wendl. | *Kauayan-kiling* | *S. curranii* Gamble | – |
| *B. vulgaris* var. *striata* (Lodd.) Gamble | Yellow bamboo, *kauayan-dilau* | *S. dielsianum* (Pilger) Merr. | – |
| *B. ventricosa* McClure | – | *S. diffusum* (Blanco) Merr. | *Bikal* |
| *B. multiplex* (Lour.) Raeusch | *Kauayan-China* | *S. fenixii* Gamble | – |
| *Dendrocalamus merrillianus* (Elm.) Elm. | *Bayog* | *S. hallieri* Gamble | – |
| *D. curranii* Gamble | – | *S. luzonicum* Gamble | – |
| *D. latiflorus* Munro | *Botong* | *S. merrillii* Gamble | – |
| *D. parviflorus* Hack | – | *S. mucronatum* Hack | – |
| *Gigantochloa aspera* Kurz | Giant bamboo | *S. palawanese* Gamble | – |
| *G. levis* (Blanco) Merr. | *Bolo* | *S. toppingii* Gamble | – |
| *G. scribneriana* Merrill | – | – | – |
| *Guadua Philippinensis* Gamble | *Guadua* | – | – |
| *Leleba floribunda* Nakai | – | – | – |
| *L. ventricosa* McClure | Buddha bamboo | – | – |
| *Phyllostachys nigra* Munro | Polevault bamboo | – | – |
| *P. bambusoides* var. *aurea* Makino | – | – | – |
| *P. pubescens* Mazel ex H. Lehaie | – | – | – |
| *P. nigra* var. *henonis* (Mitf.) Stapf. ex Rendle | – | – | – |
| *P. aurea* Carr. | – | – | – |
| *P. edulis* Makino | – | – | – |
| *Schizostachyum lima* (Blanco) Merr. | *Anos* | – | – |
| *S. brachycladum* Kurz | *Palawan Schizostachyum* | – | – |
| *S. hirtiflorum* Hack | – | – | – |
| *S. lumampao* (Blanco) Merr. | *Buho* | – | – |
| *S. textorium* (Blanco) Merr. | *Kalbang* | – | – |
| *S. zollingeri* Steud. | Yellow *buho, buhong dilau* | – | – |
| *Thyrsostachys siamensis* Gamble | – | – | – |

throughout the country except at high elevations. It is cultivated and found in backyards, along real estate boundaries and bordering rivers and creeks. It is erect, reaching a height of about 10–25 m and a diameter of 10–20 cm. It has hollow internodes 40–60 cm long and the thick walls become progressively thicker toward the lower part of the culm. A typical culm contains a large amount of silica, and, sometimes, an internode is completely filled with a hard, white siliceous mass that could damage any cutting instrument. This bamboo is rarely found in flower and the interval between flowering periods is not known. It is easily distinguishable from all other species of Philippine bamboos by its large clumps, the basal portions of which are surrounded by a densely interlaced thicket (2–3 m high) of spiny branches. This thicket, while obviously protecting the delicate young shoots from herbivorous animals, makes access to the culms exceedingly difficult.

*Bambusa vulgaris* Schrad. is claimed to have been introduced into the country during prehistoric times. It is now thinly distributed at low and medium altitudes. Most often, a clump of this species is observed growing singly and seldom in groups. Although it does not exist in abundance in any particular province, it is found in backyards, along the periphery of cultivated lands, along creeks, and at the foot of hills. It has an open or loosely clump-forming, spineless culm and reaches a height of 10–20 m and a diameter of 7–13 cm; the culm is usually yellow-green and has smaller and thinner walls and lesser strength and durability than does *B. blumeana* but is widely used for some types of furniture, toys, cages, and other essential items.

*Dendrocalamus merrillianus* Elm., a native to the Philippines, is less extensively distributed than *B. blumeana.* It is generally found growing gregariously or sometimes singly among other species and trees in the Central and Northern Luzon provinces where sporadic clumps have been observed in Tarlac, Pangasinan, La Union, and the Ilocos provinces. There are few existing clumps in Los Baños, Laguna. Although generally limited in distribution in the provinces mentioned, it can be propagated sexually or asexually anywhere in the islands at low and medium altitudes.

It is tall, attaining a height of 10–20 m and a diameter of 6–10 cm. Graceful in appearance, it has slender culms usually forming large clumps that are open or loosely tufted, with culms bending over, very thick-walled, prominently noded, but unarmed. It is used for furniture, house construction, machine shafts, etc. where great strength is desired. The tender shoots of this species are edible.

*Schizostachyum lumampao* (Blanco) Merr. is endemic to the Philippines and more sylvan than are others; erect and gregarious, it occurs extensively in some forests in Luzon. Several groves can be found in the Caraballo Mountains in Eastern Pangasinan, Camarines provinces, La Union, and the Ilocos provinces.

The culm is thin-walled and reaches a height of about 10 m and a diameter of 5–9 cm. The clumps are open, loose, and unarmed. It is strong, durable, and mainly used for making *sawali*, a construction material woven from thin strips of bamboo for houses in the rural areas.

*Schizostachyum lima* (Blanco) Merr. is endemic to the Philippines, gregarious, spineless, and erect with a dense clump. It is known to occur where *S. lumampao* occurs. Clumps can be found in Agusan, Mindoro, Rizal, Central and Northern Luzon. Those in Laguna and Quezon are widely scattered.

This species can be distinguished from other Philippine bamboos by its long internodes (0.80–1.0 m). The green culm (6–12 m high and 2.5–4.8 cm in diameter) is thin-walled (0.3–0.5 mm) and possesses linear sheath blades and nodes that are generally horizontal, although some deviate.

*Dendrocalamus latiflorus* Munro is a tall and spineless bamboo; it attains a height of 20 cm and a culm diameter of 7–12 cm. It is easily identified by its prominent and aerial roots at the nodes. It has a good prospect of utilization due to its good workability. A large plantation of this species used to be cultured for the production of edible shoots in Panabo, Davao del Norte. It is reported to be growing in Bulacan, Bataan, Rizal, Quezon, Leyte, Surigao, and Agusan.

*Gigantochloa aspera* Kurz is regarded as the giant among the bamboos on account of its towering height of about 25 m and culm diameter of 14–30 cm. Its culm surface is green with brown hairs when young and smooth when mature. A few clumps are found in Mt. Makiling and in the reforestation project in Malaybalay, Bukidnon. It has limited distribution, and there are no reports of its occurrence in other areas of the Philippines.

*G. levis* (Blanco) Merr. reaches a height of about 20 m and a culm diameter of 8–13 cm. The culm is straight, smooth, and dull green and has a siliceous and pubescent outer surface. Some clumps are growing in the Makiling Forest, whereas others are scattered in the provinces of Laguna, Batangas, and Quezon.

Although found in all parts of the country, the natural bamboo forest in the Philippines is not very extensive. Bamboos are confined to marginal lands, hillsides, along banks of rivers and streams, and in village homesteads. Bamboo forests are described to be in various stages of ecological retrogression as a result of fires, grazing, overexploitation of growing stock, etc. At present, probably, there are more bamboos in cultivated lands than in natural forests (298).

Gamble reported some 200 000 hectares of bamboo forest in the Philippines in 1910 (105), but the Bureau of Forest Development (BFD) has claimed that as of 1978 there were only 7924 hectares planted with bamboo (318). The density or stocking of these areas is not known nor is it known whether privately owned lands with bamboos are included in the figure. BFD also reported that the production of bamboos of various species was 787 223 and 426 018 culms for 1977 and 1978, respectively. It is not known, however, whether all collections were reported to the BFD (316).

A *Bambusa blumeana* forest in Cardona, Rizal, was surveyed and found to be not fully tapped. There were 28 clumps per 0.10 hectare with 25 culms per clump or a total of 7000 culms per hectare. Moreover, the estimated number of culms per hectare of *S. lumampao* is about 10000. Based on the different surveys conducted, an estimate of a natural forest of *Bambusa blumeana* was placed at about 7000–8000 culms per hectare. There was no suitable area for survey on *Bambusa vulgaris*. However, a small-scale observation was conducted at the Makiling Forest, and it was observed that the clump distribution was every 6–7 metres with 30–40 culms per clump or a total of 9000–10000 culms per hectare (427).

The Philippine Archipelago is located from 5 to 20° North of the equator. It is within the region with climatic conditions that are most favourable for the growth of *Bambusa, Schizostachyum,* and *Dendrocalamus*. The species are generally scattered from north to south in the islands. Only one species of *Phyllostachys, P. nigra* var. *henonis* (Mitf.) Stapf. ex Rendle, grows favourably in the Philippines. Other *Phyllostachys* species that were introduced survived but did not grow as expected. The Central and Northern Luzon lies between 15 and 20° North latitude — a region suitable for the growth and development of bamboos. At present, however, most lands in this region are cultivated with rice, corn, sugarcane, coconuts, and other important annual crops. It is evident that extensive bamboo plantations occurred in the area about a century ago.

Altitude also affects the distribution of bamboo with respect to form or types. The sympodial types have been observed to predominate in low and medium altitudes, whereas the monopodial type occurs more abundantly at high elevations. In Central Luzon, the largest among the islands of the Philippines, the sympodial types, particularly those belonging to the genera *Bambusa, Dendrocalamus*, and *Schizostachyum*, are found in the lowlands. At about 1500 metres altitude, some species of *Phyllostachys* (e.g., *P. aurea*) grow very well.

Altitude and temperature are related, and it is difficult to separate one from the other. For example, some species of *Phyllostachys* that grow at high elevations in the tropics occur also at low elevations in the temperate countries. It was observed that *Phyllostachys aurea* grows well in the vicinity of Baguio at an altitude of 1500 metres at about 18–26 °C. The same species grows in the high elevations (about 800–1000 metres) in Malaybalay, Bukidnon, also with a mild climate. It is interesting to note that *Phyllostachys aurea* occurs also at Kyushu, Southern Japan, at an elevation of about 50 metres, where the temperature is similar to Baguio city and its suburbs.

Some seedlings of *P. edulis* were planted in the University of the Philippines College of Forestry, College, Laguna, but their growth in height was only about 100 cm in 2 years.

Rainfall, a component of climate, necessarily affects the distribution of bamboos. There is not a single environmental factor that limits the growth of bamboos more than rainfall. Reports concerning the relationship between growth of shoots and precipitation are very few. The west and south coasts of Northern Luzon have comparatively distinct dry and rainy seasons. During the dry season, the bamboos adapt by shedding leaves and, thereby, reducing transpiration. Then, at the first splash of rain (usually late May), new buds emerge. The bamboos will then be crowned with leaves — a change that shows

Table 2. Culm characteristics of some bamboo species.

| Culm characteristics | Species[a] | | | |
|---|---|---|---|---|
| | *Bambusa blumeana* | *Bambusa vulgaris* | *Schizostachyum lumampao* | *Schizostachyum lima* |
| Length (m) | 16.2 | 12.4 | 14.2 | 12.8 |
| Green weight (kg) | 32.1 | 16.4 | 11.9 | 2.7 |
| Number of nodes (pieces) | 65 | 43 | 28 | 21 |
| Nodes at the bottom | 2.5 | 1.7 | 1.0 | 0.7 |
| Wall thickness at eye height (cm) | 1.7 | 1.1 | 0.7 | 0.4 |
| Diameter at breast height (cm) | 7.5 | 7.0 | 7.3 | 3.2 |
| Maximum internode length (cm) | 49.4 | 35.1 | 79.3 | 116.1 |
| Green weight of branches (kg) | 7.05 | 5.30 | 1.20 | 0.40 |
| Number of branches (pieces) | 30 | 32 | 14 | 12 |
| Green weight of leaves (kg) | 1.52 | 2.87 | 0.67 | 0.30 |

[a] Average of 10 culms each.

that vegetative growth in bamboos is more affected by soil moisture as a result of rainfall than by temperature. Also, bamboos retain their green leaves if they are watered. For example, bamboos growing along creeks, streams, and lakes retain their green leaves all year round even during the dry season.

Bamboos grow best on well-drained, sandy-loam to clay-loam soils derived from the river alluvium or from the underlying rocks. Seldom can one find bamboos in swampy places or in wet streambeds. Soils that are suitable for bamboo growing vary from yellow, through reddish yellow, to brown-yellow. A pH of about 5–6.5 is most suitable for bamboos as well as many other plants. Soils along salty bodies of water are not good for the development of bamboos.

In Cardona, Rizal, and vicinities, about 38 km northeast of Manila, bamboos grow well on well-drained, stony soils varying from dark brown to light red. Along the west coast of Northern Luzon, the soil is a dull, reddish brown and dull, yellowish brown.

Bamboos grow bigger, both in diameter and height, in places with high humidity and fertile soils. Bamboos that grow in moist soils generally have larger leaves than do those species growing in drier sites.

Bamboo shoots start to grow during the wet or rainy season. Although it is known that the increased soil moisture and the decreased temperature during this season influence the emergence of shoots, data on the rate of growth and the quality of shoots are needed for the improvement of silvicultural techniques in the Philippines.

Results of an experiment conducted in the provisional nursery of the Forest Products Research and Industries Development Commission (FORPRIDECOM) showed a precise relationship between growth period and elongation. In tropical bamboo species, the sprouting period is long, and, during it, very few leaves appear on the mother culm. The early sprouts grow slowly, but those that emerge later grow more quickly so that the amount of elongation is bigger in the later part of the rainy season.

In 1976, the first shoot of *Bambusa vulgaris* emerged on 1 April, whereas the last shoot was observed on 2 November — a sprouting period of 216 days. The shoots that emerged during the month of April and May (early growers) were found to have attained lower height than those that appeared during October and November (late growers). Furthermore, the early growers had shorter growth days than the late growers, but the difference was not significant. *B. vulgaris* has 40–80 days growth period.

Generally, the bamboo culm is hollow inside, wide at the base and narrower at the top. The culm-wall thickness, likewise, varies from very thick at the base to thin at the top. The maximum diameter of culms of *Bambusa blumeana* is about 6 metres above the ground; *B. vulgaris* 4 m; *Schizostachyum lumampao* 5 m; *S. lima* 2 m; thus the maximum diameter along the length of the culm is not at ground level. Maximum culm-wall thickness starts at about 3.5 cm above the ground for *B. blumeana*; 1.5 cm for both *B. vulgaris* and *S. lumampao*, and 0.8 cm for *S. lima*.

For all the species studied, the length of internode is shortest near the ground. This increases to a certain point and shortens gradually toward the top. The longest internode for all species is located about 2–3 metres above the first branch of the clear culm. The maximum diameter appears well below the longest internode (Table 2) (427).

In a separate study, Tandug (418) found that *B. blumeana* has an average diameter at the base of 9.18 cm, *Gigantochloa levis* 8.61 cm, *Dendrocalamus merrillianus* 5.99 cm, and *Schizostachyum lumampao* 4.96 cm. Although *D.*

*merrillianus* is small-sized, it has the thickest culm wall at the base (2.54 cm) followed by *G. levis* (1.78 cm); *B. blumeana* has the thickest culm wall at the apex (1.08 cm), and *S. lumampao* has the thinnest culm wall at the base (0.63 cm) and at the apex (0.29 cm). Species with bigger diameters were observed to produce longer culms.

**Propagation and Cultivation**

Some bamboo species produce seeds that germinate readily. However, because most bamboos flower infrequently and a large number of species produce sterile seeds when they bloom, propagation by seeds cannot be depended upon. Instances of bamboo flowering and sexual propagation have been observed for the following species:

•*Bonkawe*, in Cardona Rizal, flowered in September 1976. The seeds were already matured when flowering was observed, and the mother culms had dried. Seedlings with 2-3 leaves started to grow 3-4 weeks after germination. The culms that did not flower in September 1976 flowered in April 1977 and produced matured seeds in June 1977. The matured seeds were brown and readily germinated on the ground. The seedlings planted in nursery plots attained a height of 105 cm and a diameter of 8.1 mm, ready to be transplanted to the field. Potted seedlings were smaller than were those planted directly in nursery plots. It is therefore advisable to transplant potted seedlings at age 3 months (427).

•*Schizostachyum lumampao* was observed in flower toward the middle of September 1976 at the University of the Philippines, Los Baños, College of Forestry. The date of flowering was uncertain, but the presence of many seedlings on the ground showed a high germination rate of the species. Seedlings were also found to have germinated on the basal portion of branches (427). Planting seeds of this species was tried in Nueva Vizcaya and Makiling Forest in 1964 and 1980 respectively. Results of these trial plantings showed that this species can be successfully propagated by seeds (35, 62).

•*Bambusa arundinacea* Willd. seeds with 74.1% viability were brought from Thailand to the Philippines for trial planting. The seeds germinated 1 week after being sown. Each seedling had different growth development, depending upon the size of the seed. Larger seeds grew faster than did the small ones. Growth development was good, and these seedlings appeared suitable for planting on mountain sites (427).

•*Phyllostachys edulis* Makino seeds collected in Japan in August 1974 were planted in the Philippines in April 1975. They were sown in pots, and the seedlings attained a height of 25 cm after 4 months at which time they were planted in nursery plots. After 2 years, the seedlings resembled those of shrubs, having an abnormal growth resembling the sympodial type of tropical bamboos. Six months later, new culms developed from the rhizome buds, showing a monopodial type of regeneration.

Regeneration by seedlings is much slower than that by cuttings. The growth development of seedlings is highly affected by rate of fertilizer application. *Bonkawe* and *Schizostachyum lumampao* exhibited better growth 280 days after application of NPK fertilizer (50 kg/0.1 ha and 100 kg/0.1 ha) than did control seedlings, although *B. arundinacea* showed no response to fertilizer treatments (427).

Asexual propagation is through the use of rhizomes or offsets, cuttings, layering, and marcotting. Rhizomes and cuttings are most often used; however, the use of rhizomes is limited to nonclump-forming species (427).

Curran and Foxworthy conducted in 1912 the first study on the propagation and growth of Philippine bamboos. Survival rates for cuttings of *Bambusa blumeana, B. vulgaris,* and *Gigantochloa levis* were 34%, 32%, and 6% respectively. Most of the culms were still small 5 years after being planted; the exceptions were seven clumps of *B. blumeana*, which attained a height of more than 15 m. It was observed that *B. blumeana* and *B. vulgaris* started to grow during the later part of the dry season but at a very slow rate until the rainy season. *G. levis* was observed to start growing about the beginning of the rainy season, exhibiting rapid growth in the latter part of the period. These three species were observed to have attained their full height in about 5 months with their average daily growth being 17 cm (*B. blumeana*), 13 cm (*B. vulgaris*), and 13 cm (*G. levis*) (57).

A second study was conducted by Foxworthy in 1917 in a 2-hectare plot planted only with *B. blumeana*; 59% of the stump cuttings and 40% of the culm cuttings survived after a year (57). Another study on *B. blumeana* showed a greater percentage of survival (60.80%) in culm cuttings planted unsplit (61). For *G. levis*, unsplit cuttings also gave better results, and the middle and top portions of the culm were the best material for propagation (4).

Chinte (70) made use of 1-year-old culms cut into three-node and two-node sections, planting each cutting obliquely with two nodes and one node buried respectively. He reported a 59.96% survival for *B. vulgaris* and 27.67% for *G. aspera*, whereas *B. blumeana* and *G. levis* failed to grow. Three-node cuttings were found to survive better than two-node planting stocks, and the basal sections were superior to the middle and top sections.

Mabayag (225) found that *B. blumeana* cuttings sprouted and survived better under direct sunlight than they did under full shade and that the basal portions of *B. blumeana* culm cuttings were better than the middle and top portions of the culm.

Studies on *B. vulgaris* showed that planting materials taken from 6-month-old culms gave better results than did those obtained from 1-year- and 2-year-old culms. Horizontal planting of unsplit stock proved better than did vertical planting. Best results are possible from materials planted late in the rainy season and watered on days when it does not rain (427).

In a separate study of a total of 720 two-node split and unsplit (about 1-2-year-old) culm cuttings directly planted in a cogonal area, the field survival rates after 6 months were *B. blumeana* 25%, *B. vulgaris* 51%, and *D. merrillianus* 35%. *G. aspera* had 94.25%, 32.22%, and 11.66% field survival rates at 1 month, 3 months, and 15 months respectively; *S. lumampao* failed to grow. In all species, higher survival rates were observed with unsplit cuttings and with weeding (34).

Ordinary methods of preparing planting stock have low rooting rates, and there appears a need for plant-growth regulators. Results of a study by Uchimura (427) showed that *B. vulgaris* planting stock the base of which was immersed in 100 ppm solution of indole butyric acid (IBA) for 24 hours before being planted achieved better rooting rates and longer roots than did stock soaked in alpha-naphthalene acetic acid (NAA) and alpha-indole acetic acid (IAA).

In a similar study using *B. blumeana* and different levels of NAA, IAA, and IBA, 600 ppm NAA gave the highest total dry weight and mean length of roots, and 200 ppm gave the highest mean number of roots among the different growth regulators studied (58).

Suzuki and Ordinario (408) obtained 45% survival of *B. blumeana* treated with indole butyric acid and 32% for untreated controls; 80% for treated *B.*

*vulgaris* and 75% for untreated; 60% for treated *D. merrillianus* and 53.50% for the untreated. They took all survival counts 3 months after planting and found that *S. lumampao* and *S. lima* cannot be easily propagated by culm cuttings (298).

Cabanday (61) reported a 69.90% survival of 123 marcots of *B. blumeana* — a higher percentage than was obtained with cuttings. The procedure consisted of making an undercut at the basal part of the culm in such a way that a sizable portion of the culm allowed passage of elaborated food materials. The culm was then bent and supported with a strong prop; the branch at each node was pruned to about 2.5 cm with care so that the dormant buds were not injured. An admixture of garden soil and leaf mould was placed around each node, wrapped with coconut husk or coir, and securely tied with wire at both ends.

Cabanday (61) obtained a survival of 27.70% for *B. blumeana* by ground layering 1-year-old culms pruned of branches. The culms were half-buried in the ground in such a manner that the buds along each side of the culm were in a lateral position. A lower survival rate was obtained when the entire culm was buried deeper and totally covered with soil.

Planting of rhizomes or offsets is usually done with 1-year-old culms that are excavated along with their root system. The culm may be cut to about 1 m high and planted during the rainy season. The disadvantage of this method lies in the high cost of labour for excavation and transportation of the bulky planting stock. However, it is the only possible way to propagate asexually *S. lumampao* and *S. lima*. Uchimura (427) succeeded in propagating *S. lumampao* by this method.

**Management and Harvesting**

Systematic and selective cutting of matured culms ensures the continuous production of young shoots, an index of annual yield or increment. The impressive growth and regenerative characteristics of bamboo and the high potential for industrial uses are important factors in its successful management. The exploitation of bamboo plantations needs to be regulated on a sustained-yield basis (457).

The recovery of stands of *S. lumampao* was observed in 1917. All culms were cut and cleared from the area, and a considerable number of years was required for this species to regain its original density (57) — a finding that militates against clear-felling if yield is to be sustained.

A growth and yield study of *B. blumeana*, *B. vulgaris* var. *striata*, and *G. aspera* was conducted in areas of Surigao del Sur that had been logged. Cuttings of *B. vulgaris* in an area cleared one or two times a year gave only 57% survival, whereas untended cuttings gave only 35%. Cuttings of *G. aspera* and *B. vulgaris* var. *striata* produced survival rates of 28% and 60%, respectively. At 3–4 years cutting age, *B. vulgaris* gave an annual yield of 2.4–2.8 tonnes of pulp per hectare. This amount falls within the sustained-yield range of 1.6–9.1 tonnes in the bamboo forests of Burma, India, and Pakistan. For *B. vulgaris* var. *striata* and *G. aspera*, yields per hectare were quite low, ranging from 0.5 to 0.7 tonnes and from 0.3 to 0.4 tonnes, respectively. *B. blumeana* and *G. levis* failed to grow (70, 457).

For cutting or harvesting, bolos and hatchets are generally used. Culms, 3 or more years old, are ready for harvesting, those of unarmed bamboos usually being cut close to the ground and those of bamboos such as *B. blumeana* being cut 2–3 m above the ground (just above the dense growth of spiny branches, the very thick-walled portion of the culms being left in the clump). Harvesting is usually done during the dry season, from November to May. In practice, newly cut bamboos are often kept in running water for several weeks so that their starch content will be decreased, and they will, thus, be rendered less attractive to powder-post beetles (224).

The manner of clump treatment and harvesting still needs some study. Preliminary results of a study on *B. blumeana* indicated that removal of spines and the cutting of culms close to the ground increased the number of shoots that appeared each year and reduced shoot mortality. The removal of spines also reduced the number of deformed culms because the shoots no longer had to work their way through the thicket of spines. Regular cleaning of the clumps also facilitated the harvesting of culms (298).

**Research Needs, Problems, and Recommendations**

An assessment of past research on bamboo in the Philippines reveals that the available information is far from adequate to serve as a guide for proper management. The studies so far have limited application because they conflict on important factors or variables that may have significant effects on the growth, yield, and rotation.

*Survey:* A survey to determine the actual extent and distribution of the different species of bamboos in the Philippines must be conducted. A study on this has been proposed and approved but has not yet been implemented due to a lack of funds.

*Taxonomy:* The Philippines needs thorough and satisfactory taxonomic studies on bamboos and the exploitation of their technologic potentialities. At present, there are still a number of unidentified bamboo species existing in the Philippines and even a greater number are not fully tapped. Not one Filipino taxonomist is involved in the taxonomic studies of Philippine bamboos, and Filipino researchers should be encouraged to undertake training on the taxonomy of bamboos.

*Phenology:* A gap in information exists in the phenology of bamboos and must be filled as a basis for all aspects of bamboo research. In bamboo flowering, factors like differentiation of flower buds, causes of flowering structures in different species, and recovery after flowering need further study. The period of flowering differs by species. Some bamboo species produce seeds that germinate readily. However, sexual propagation by seeds is impractical and unreliable because the flowering of bamboos is, in most cases, a very unusual occurrence. Besides, some flowering species produce sterile seeds. Some species die within 1–2 years after flowering; others do not die, but their vegetative growth is slowed down during the flowering stage. Seed collection is best when the seeds mature in the mother plant, and the branches are cut before the seeds fall naturally. Natural drying of seeds follows (57).

*Protection of bamboo shoots:* Information available indicates that only 50–70% of the shoots emerging from the clump grow to maturity. Causes of mortality other than typhoons are unknown. There is, therefore, an urgent need to determine the causes and find effective prevention and control measures.

*Propagation:* At present, bamboos are commonly propagated by asexual means, i.e., culm cuttings, rhizome cuttings (offsets), and layering. These methods are very laborious and slow.

Asexual propagation is done during the late rainy season. The planting material is placed 10–20 cm below the ground and then covered with soil. Some leaves are removed from the planting material in an effort to reduce wilting due to overexposure to sunlight. Further study on the effect of light intensity on growth of the culm from seedlings is suggested. Another important consideration in asexual propagation is the survival rate of roots.

Tissue culture, an advanced technique whereby the juvenile tissues of a culm are cut and grown artificially on suitable medium under aseptic conditions, is worthy of investigation. This advanced technique offers great promise for rapid propagation on a large scale, especially species of bamboos with desirable characteristics. Sugarcane, a Gramineae, has been responsive to this technique, and there are high hopes that it will be successful with bamboos.

Storage and germination studies must be conducted for species that produce fertile seeds, and asexual methods of propagation must be improved. The age, portion of culm, number of nodes, and planting position for different species need to be investigated. Knowledge of effective propagation methods for a given species under various site conditions is necessary (457).

*Management and harvesting:* Fertilization studies should include dosage and time of application and tests on individual and mixed combinations of NPK elements.

There are no rules that regulate felling of bamboos, unlike timber harvesting where specific tree-marking rules are implemented by trained tree markers. Felling of bamboos has not yet been improved, and some faulty practices are cutting without due regard for the even distribution of the remaining culms; cutting above the spines, leaving about 3–5-m long stumps that are seldom used; cutting too much along the periphery and, thus, hindering expansion of the clumps; not clearing the clumps of deformed and dead culms; cutting out of season; and cutting immature culms. Determination of optimum stocking or spacing that will give maximum yield is important in management of bamboo plantations (457).

In times of great demand for raw materials, the owners usually cut the good-quality culms, leaving the overmature and poor-quality culms in the clump. This causes a considerable decline in productivity and failure to meet increasing demands.

Selective cutting, if conducted properly, is an efficient tool for improving poor groves. A bamboo culm that has reached maturity must be cut; otherwise it becomes overmature and loses its vigour. Old culms adversely affect the growth and quality of young culms and crowd them (407). The most important factor to consider here is the relationship between the stand structure and productivity, i.e., how many culms are to be cut and to be left. Unfortunately, there is a dearth of knowledge and technique on the rational selective-felling method of bamboos in the Philippines.

The effect of period and quantity of harvest and divided harvesting of clump in relation to bamboo growth has to be investigated further.

Research on the effect of age of culm and growth regulators on pulp yield and other important products should also be conducted to be used as a guideline in the management of bamboo for a given product, as the optimum rotation is directly related to the end-use (457).

*Development potentials (13):* There are some potential uses of bamboos that are not given due importance or recognition. This might be due to the limited information on bamboos. Some of them are landscaping and ornamentals, especially for species like *Bambusa vulgaris* var. *striata* and other small-sized species; hedges and windbreaks, particularly the small-sized bamboos; erosion control; reforestation with bamboo clumps that reproduce themselves and can be left alone or intensively managed; watershed crops mixed with trees; and expansion of existing cottage industries through shared and new technologies.

# Sri Lanka

Fourteen species of bamboo have been reported to be growing in Sri Lanka, and of these only five species (*Bambusa orientalis, B. vulgaris, B. vulgaris* var. *vittata, Dendrocalamus giganteus,* and *Ochlandra stridula*) are widely used. The first four species are used for scaffolding, manufacture of curios and handicrafts. *O. stridula* is used as a support for bean vines in the highlands. These five species, though widely used, have never been cultivated on a systematic basis, and there is hardly any research done on either their propagation or their utilization.

A part of the long-fibre requirement of the local paper industry, which has been relying on imported bamboos, is to be met by *Dendrocalamus strictus* grown in the dry zone where land is plentiful. The research activities related to the silviculture of *D. strictus* based on local experience are discussed. In view of the importance of bamboo in the local economy, it is suggested that the cultivation of bamboo and its silviculture be given more importance in the future.

Sri Lanka (Ceylon) lies between 5°55″ and 9°55″ N and 79°41″ and 81°54″ E. The total area of the island is 6.4 million hectares. The island could be demarcated into two clearly defined climatic zones, the dry zone and the wet zone with an intermediate zone in between. Nearly 66% (two-thirds) of the island constitutes the dry zone, mainly flat and undulating land. The wet zone is situated in the south and southwestern region of the island and consists of the coastal plains and very rugged mountainous terrain rising up to an elevation of 2750 metres. The mean monthly temperature varies from 30 °C in the lowlands to 20 °C in the highlands (higher than 2000 metres). The annual rainfall varies from 1250 mm to 1850 mm in the dry zone and 2500 mm to 5000 mm in parts of the wet zone. The total population is nearly 14 million people.

Of the 6.6 million hectares of land in Sri Lanka, 4.2 million hectares fall in the dry zone and 1.5 million hectares in the wet zone; about 0.9 million hectares fall in the intermediate zone. According to an estimate made in 1970, natural forests in the dry zone constitute 2.1 million hectares; in the wet zone, 0.2 million hectares; and in the intermediate zone, 0.1 million hectares.

The natural forests of Sri Lanka contain more than 100 indigenous timber species. The majority are found in the wet zone; the dry zone and the drier parts of the montane zone contain fewer valuable species and the stocking is extremely poor.

At present, the total timber production from all the natural forests of Sri Lanka consists of about 200 000 cubic metres. Both the dry zone and the wet zone contribute nearly equally to the total timber production.

*The author K. Vivekanandan (Research Division, Forest Department, Colombo) presented this paper.*

Although the extent of natural forests in the dry zone is large (nearly 86%), the bulk of it is unproductive or low-yielding. This fact, together with expansion of agricultural activity in this region, is resulting in the decrease in forest area and the gradual diminishing of timber resources. Of the 0.2 million hectares in the wet zone, only 9% constitute forest reserves — classified as protection forests.

However, to compensate the loss in timber production from the natural forests of these two zones, forestry personnel are establishing extensive forests with proven species of exotics. During the past decade there has been substantial planting of exotic species in the two zones, and there were more than 80 000 hectares up to the end of 1979.

## Species of Bamboo in Sri Lanka

Fourteen species of bamboo have been reported to be growing in Sri Lanka (362); they comprise *Bambusa orientalis, B. vulgaris, B. vulgaris* var. *vittata, B. multiplex, Dendrocalamus giganteus, Chimonobambusa densifolia, Indocalamus walkerianus, I. deblis, I. floribundus, I. wightianus, Ochlandra stridula, O. stridula* var. *maculata, Teinostachyum attenuatum,* and *Oxytenanthera monadelpha*. Of these, only those of *Bambusa, Dendrocalamus,* and *Ochlandra* are considered important from the utilization point of view.

Bamboos in Sri Lanka grow in all climatic zones, but the greatest development is in the intermediate, wet, and montane zones. The dry zone has fewer species, confined mainly to banks of rivers. The very dry areas are totally devoid of bamboos.

## Extent and Cultivation of Bamboo

There is no accurate estimate of the extent of different species of bamboos grown in Sri Lanka, and, furthermore, there has not been any organized attempt to cultivate the different economically important species on a large scale. The Forest Department up to recent times had been concentrating mainly on the massive reforestation program with tree species on the island to meet the future timber needs and had paid little attention to the cultivation of bamboos. As a result, knowledge of artificial propagation of bamboo in Sri Lanka is seriously lacking. In the mid-1960s, however, the Forest Department embarked on a program of cultivating *D. strictus* in the dry zone with a view to meeting the requirement of the paper industry.

The island's first paper factory is located at Valaichenai in the east coast in the dry zone. Its raw materials are mainly rice straw and imported long-fibred, coniferous pulp.

As a result of a feasibility study, it was decided to use *D. strictus* to meet at least part of the requirement for long fibre. To pursue this policy, the Forest Department embarked on a program cultivating *D. strictus* in the vicinity of the paper factory where land was plentiful. When the department attempted to plant this species there was hardly any local experience.

In 1964, 10 kilograms of seed and 2000 rhizomes were air-lifted from a private seed merchant in Dehra Dun. The rhizomes were planted in weeded patches under young teak. The venture proved an absolute failure, although the seeds germinated satisfactorily and were transplanted in the field.

To cater to an annual reforestation target of 200 hectares of *D. strictus*, the

*A 5-year-old trial plot of Dendrocalamus strictus in Sri Lanka.*

department felt that the methods of germination, raising of plants, and other nursery practices must be perfected. Thus, it undertook some research and recorded the findings.

To determine the effects of pretreatment of seeds, researchers soaked the seeds in water for different periods ranging from 24 to 96 hours. The germination rates for soaked seeds were not significantly different from those for untreated ones; percentages for untreated seeds and for seeds soaked for 24, 48, and 96 hours, respectively, were 57.3, 58.6, 55.4, and 56.8. Hence, nursery seeds have since been given no treatment before being planted.

One of the main difficulties experienced with seeds of *D. strictus* procured from India was the rapid loss of viability. This phenomenon is common to all bamboos, and it was thought necessary to retain viability by resorting to cold storage. Seeds were stored at 0, 15, and 30 °C in sealed containers, and samples were tested monthly. Seeds stored at 30 °C had a viability almost zero after 1 month, whereas those stored at 0 °C and 15 °C maintained viability much longer. After about 8 months, seeds stored at 0 °C had a higher germination rate than those at 15 °C, so this temperature is now recommended for storage.

Initially, the planting stock was raised in nursery beds. The seeds were drill sown at spacings of 23 × 23 cm, five seeds per space. After the seedlings attained a height of about 1.5–2 metres, their aerial portion was cut off, and they were transplanted. This method gave rise to a large number of casualties.

To overcome the drawbacks, the researchers sowed seeds in 23 × 23 cm polythene bags and the seedlings were transplanted when they were about 1 year old. This method gave excellent survival rates.

To work out a system of thinning, personnel conducted experiments in one of the oldest plots. The treatments used were (1) no thinning, (2) removal of all dead and deformed culms, (3) retention of all new culms and three-fourths of old culms, (4) retention of all new culms and one-half the old culms, (5) retention of all new culms and one-fourth the old culms, and (6) removal of half of both the old and the new culms. The mean numbers of new culms developed at the end of the first year for each treatment were (1) 43, (2) 52, (3) 44, (4) 38, (5) 43, and (6) 48. From the results, it appeared that removal of all dead and deformed culms (2) promoted the development of new culms best, but as a compromise, removal of half of both the old and the new culms (6) was considered satisfactory and manageable.

The total area under *D. strictus* at the end of 1975 was 1150 hectares as a pure crop and 370 hectares as a mixed crop with *E. camaldulensis*. In 1975 the planting of *D. strictus* was suspended because of the difficulty in obtaining seed from India; the occurrence of fires in the plantations; the damage due to elephants; and the fact that the National Paper Corporation was not geared to use it as a raw material.

## Future of Bamboo in Sri Lanka

The three species of bamboo widely used in Sri Lanka are *Bambusa vulgaris, Dendrocalamus giganteus* (for scaffolding and rural housing), and *Ochlandra stridula* (as support for bean vines). At present, these species are not cultivated on a systematic scale. It is felt that very soon the demand for them will outstrip their supply; thus it is imperative that some steps be taken to propagate these species artificially. The Forest Department is now contemplating the planting of bamboos under its normal reforestation program and under the community forestry program in the Mahaweli River Development areas.

Up to now research activities have been confined mainly to tree species, bamboo being totally neglected. With the gradual decrease in the bamboo population in the country, it has become necessary to direct research activities toward the development of bamboo. In the next few years, the Research Division of the Forest Department expects to undertake trials with species from other countries, varietal selections, studies on improvement of nursery stock and seed storage, and the introduction of better management and utilization methods.

# Thailand

Background information on the status of bamboo forests in Thailand is briefly given, and some mention is made of the bamboos locally used in handicrafts, industry, food, and housing. The activities of the Bamboo Research Station at Kanchanaburi Province in southwestern Thailand are noted, especially the natural regeneration and nursery techniques so far achieved.

A brief report on the management of *Thyrsostachys siamensis* Gamble and *Bambusa arundinacea* Willd., which occur abundantly and naturally, is presented. The annual culm production of *T. siamensis* is 2500–3000 culms/hectare, or 8.8–14.9 tonnes/hectare. Production of *B. arundinacea* is approximately 24.7 tonnes/hectare. Data on the harvesting of both species are also given together with information on their export and import.

The kingdom of Thailand is located in the Indochinese peninsula of Southeast Asia, between 5 and 21° N latitude and 97 and 105° E longitude. The total land area is about 513 000 square kilometres. The total population is approximately 48 million. The forest types are varied, ranging from tropical, evergreen forests on the peninsula (average annual rainfall more than 2000 mm) to the dry, deciduous, dipterocarp forest scattered in the northern, central, and northeastern parts of the country with annual rainfall of approximately 1000 mm.

Due to the tropical climate, the species of bamboo are abundant. It is estimated that more than half of the bamboo species in the world can be found in Thailand. The bamboos grow naturally either as scattered undergrowths in all forest types or as almost pure stands, such as *Thyrsostachys siamensis* Oliv. and *Bambusa arundinacea* Willd.

In the North, bamboos grow in the teak forests, and, in other parts of the country, they are undergrowth in evergreen or mixed, deciduous forests.

Most bamboo species in Thailand belong to the sympodial type; in fact the only monopodial bamboo so far recorded in Thailand — *Pseudosasa* — was found in 1966 in the North. The many attempts to introduce the monopodial type from the temperate countries into Thailand have been without success.

The important species of bamboos used in handicrafts, industry, food, and housing are *B. arundinacea* (*Phai paa*); *B. blumeana* Schult. (*Phai seesuk*); *B. nana* Roxb. (*Phai lueang*); *B. polymorpha* Munro (*Phai hom*); *B. tulda* Roxb. (*Phai bong*); *Dendrocalamus asper* Back. (*Phai tong*); *D. brandisi* Kurz (*Phai bong yai*); *D. hamiltonii* Nees (*Phai hok*); *D. longispathus* Kurz (*Phai lammalok*); *D. membranaceus* Munro (*Phai sang*); *D. strictus* Nees (*Phai sang nam*); *B. vulgaris* Schrad. (*Phai lueang*); *Cephalostachyum pergracile* Munro

*This paper was presented in two parts by its authors Tem Smitinand and Sakonsak Ramyarangsi, who are both with the Royal Forest Department in Bangkok.*

(*Phai khaao laam*); *C. virgatum* Kurz (*Phai hiae*); *Gigantochloa albociliata* Munro (*Phai rai*); *G. nigrociliata* Kurz (*Phai phak*); *G. hasskarliana* Back. ex Heyne (*Phai phak man*); *G. macrostachys* Kurz (*Phai pok lam*); *Thyrsostachys oliveri* Gamble (*Phai ruak dam*); and *T. siamensis* Oliv. (*Phai ruak*).

## Distribution

The taxonomy of bamboo species in Thailand is still in its infancy; at present it is estimated that there are 12 genera and 41 species (Table 1). More species are expected to be found in the Tenasserim mountain range along the border of Burma and the Kalakhiri range along the border of Malaysia. The distribution of the species varies with climate, soil fertility, and elevation, although some species such as *B. arundinacea, T. siamensis*, and *G. albociliata* have very wide distribution. Some bamboos occur only in a particular area; examples are *Schizostachyum zollingeri* Steud. and *G. hasskarliana*, which are confined to the peninsula in the tropical rain forest. *D. giganteus, D. hamiltonii, D. sericeus* Munro, *Melocalamus compactiflorus* Benth., and *Teinostachyum griffithii* Munro occur in the hills in the North. In the dry, deciduous, dipterocarp forest, the grass-like bamboos, *Arundinaria ciliata* A. Camus and *A. pusilla* A. Chev. and A. Camus, are preponderant. *B. arundinacea* often occurs along the riverbanks and water courses in the lowland, but *B. tulda* and *T. oliveri* prefer the deep soil in the valley, where the relative humidity is high.

Some species are known either from only one collection or from the literature and thus can be classified as less-known species; they include *D. dumosus* (Ridl.) Holttum from Rawai Island, Satun; *B. pierrei* E.G. Camus; *B. wamin* Brandis from Chiang Mai; *O. stocksii* Munro from Nakhon Phanom; *O. hosseusii* Pilger from Nakhon Thai, Phitsanulok; *S. insulare* Ridley from Rawai Island, Satun; and *S. longispiculatum* Kurz.

## Natural Regeneration

Besides vegetative regeneration occurring seasonally, bamboos occasionally produce seeds as a means of reproductive regeneration. Because of the wide distribution, one can come across bamboo of nearly all species

Table 1. Bamboo species found in aerial survey and ground check of Thailand.

| Region | Common species | Area (approximate ha) |
|---|---|---|
| Central Region | *Thyrsostachys siamensis,* | 450 000 |
| (Kanchanaburi, | *Bambusa arundinacea,* | 250 000 |
| Khao Hin Lap, | *Dendrocalamus longispathus,* | |
| Erawan Srisawat) | *Dendrocalamus strictus,* and others | 100 000 |
| Northern (Lampang, Ngao) | *T. siamensis, T. oliveri, B. arundinacea, B. blumeana, Gigantochloa albociliata, B. tulda, D. membranaceus, Schizostachyum aciculare,* and others | >100 000 |
| Southern (Surat thani) | *Oxytenanthera hosseusii, Gigantochloa nigrociliata, B. arundinacea, S. aciculare, S. zollingeri* | >100 000 |

flowering every year in Thailand. There are both gregarious and sporadic flowering species. Flowering is during December–January, and the fruits or seeds are fully mature by early April. It has been estimated that bamboo will flower at age 30–60 years, but the phenologic study of bamboo species in Thailand is just starting. At the Bamboo Research Station, many important species have been grown, with the researchers' objective being to determine the flowering age. At present, the oldest experimental plots grown from seeds in Thailand are 15 years.

When fully mature, the fruits or seeds fall to the ground and wait to be germinated; the mother clump dries up and dies eventually. The seeds germinate during the following rainy season. Seedlings establish themselves in the following year with small culms; and by the age of 10 years have developed complete culms, equal in number and size to their parents'.

Observations have shown that vegetative parts, taken from a particular clump 1 or 2 years before the clump flowers, produce flowers and die at the same time as the parent clump. This is noteworthy for physiologic studies.

Although many seeds may be produced by a particular clump, they are usually depleted by animals such as jungle fowl, birds, and squirrels. Another very important hazard is forest fire, which destroys both seeds and seedlings and is important in the distribution of bamboo forests.

## Nursery Techniques

It is obvious that bamboos are economically important in the tropical world, especially in developing countries like Thailand. Their role in the life of rural peoples extends to housing, food, handicrafts, and small industry. Realizing the importance of bamboos, the Thai–Japanese Bamboo Study Project established a research centre to study bamboo. Most of the research at the centre deals with the selection of suitable species that can be grown as a cash crop; studies cover the growth, yield, effect of fertilization, propagation, irrigation, flowering, etc. Table 2 summarizes some of the findings.

## Structure of Bamboo Forests

At present, studies on bamboo have concentrated on *T. siamensis* and *B. arundinacea*. *T. siamensis* groves normally have 200–300 clumps/hectare, and in each clump there are 30–100 culms. Poor stands are usually due to low-fertility soils, and because *T. siamensis* mostly occurs on low-fertility soils, 30 culms/clump is considered to be dense. If there are 100 culms in each clump, the crop is very dense and difficult to cut. Thus *T. siamensis* normally produces approximately 1500 culms/hectare, whereas *B. arundinacea* produces 5000–8000.

The yearly increment per unit area is dependent on the number of new culms produced each year. The number of new culms varies such that large yields occur in alternate years — "on" years and "off" years. The annual increment is the average of the production in two consecutive years.

In "on" years, not only is the number of culms produced greater but also the size of the culms is larger. If fertilizer is applied, the amount and size of culms are increased still further.

Information from small experimental plots of *T. siamensis* and *B. arundinacea* (Table 3) can be extrapolated as an estimation of culms production

Table 2. Research findings on some species in Thailand.

| Species | DBH[a] (cm) | Branches | Wall thickness of culm | Density of culms in a clump | Mixed growth with trees | Soil quality and other comments |
|---|---|---|---|---|---|---|
| *T. siamensis* | 2–3–6 | Small; spread from upper third of culm | Solid in lower part | Tufted | Slightly mixed with trees | Dry and poor soil |
| *B. arundinacea* | 3–8–15 | A number, large and thorny; spread from lower part of culm | Thick | Rather tufted | Slightly mixed with trees | Wet soil, especially riverside and around farmhouses |
| *B. blumeana* | 3–7–10 | Thorny; spreading like that of *B. arundinacea* | Thick | Rather tufted | Slightly mixed with trees | Wet soil, riverside and around farmhouses |
| *B. tulda* | 3–7–10 | Thornless | Rather thick | Rather tufted | Slightly mixed with trees | Rather fertile land, riverside |
| *D. longispathus* | 5–6–10 | Slender; spread from upper third of culm | Thick | Rather sparse | Slightly mixed with trees | Rather fertile soil; riverside |
| *D. membranaceus* | 3–6–10 | Thornless; spread from upper third of culm | Thin | Rather sparse | Slightly mixed with trees | Rather fertile soil and mountainous districts |
| *G. albociliata* | 1–2–3 | Spread from lower part of culm | Rather thick | Rather tufted | Undergrowth of teak | Rather fertile soil and mountainous districts |
| *G. nigrociliata* | 3–6–10 | Spread from upper third of culm | Thick | Rather tufted | Mixed with trees | Fertile soil and gentle slopes |
| *O. hosseusii* | 1–2–3 | Numerous | Thick | Rather tufted | Undergrowth of dipterocarp | Poor soil |
| *S. aciculare* | 1–2–3 | Rather numerous | Thin | Rather sparse | Undergrowth of trees | Rather fertile soil |
| *S. zollingeri* | 2–3–6 | Few | Rather thin | Rather sparse | Mixed with trees | Rather fertile soil |

[a] Diameters at breast height.

Table 3. Production of bamboos in 1964 research studies. [a]

| Species | Location | Plot size (m) | New culms | 1-year culms (kg) | 2-year culms (kg) | Remarks |
|---|---|---|---|---|---|---|
| *T. siamensis* | Hin Lap | 10 × 20 | 166 | 298.3 | 370.2 | Diameter |
| *T. siamensis* | Hin Lap | 10 × 10 | 78 | 148.3 | 235.9 | <4 cm |
| *T. siamensis* | Erawan | 10 × 10 | 13 | 87.9 | 1003.9 | Diameter >4 cm |
| *B. arundinacea* | Hin Lap | 10 × 10 | 23 | 246.6 | 634.5 | |

[a] Production figures are from an "on" year; those for an "off" year would be about one-half.

Table 4. Growing stocks of bamboo in north Kanchanaburi province.

| Species | Culms (over 3 years old) | Culms (1–2 years old) |
|---|---|---|
| *T. siamensis* | 44 758 000 | 21 339 000 |
| *O. nigrociliata* | 29 481 000 | 12 352 000 |
| *B. arundinacea* | 8 454 000 | 2 879 000 |
| *D. strictus* | 13 066 000 | 5 081 000 |
| *M. compactiflorus* | 22 836 000 | 6 629 000 |
| *B. brandisi* | 134 000 | 69 000 |

per unit area, although the figures would probably overestimate the situation due to the uneven distribution of culms in natural stands. It is estimated that annual production from *T. siamensis* is 2500–3000 culms/hectare.

From these studies, it was shown that the yearly production of *T. siamensis* was between 8.8 and 14.9 tonnes/hectare and that of *B. arundinacea* approximately 24.7 t/hectare. Because the information has been extracted from plots in the "on" year, the amount for the "off" year would be one-half to one-third approximately. Therefore in *T. siamensis* weight would be 3–5 tonnes, and 5–8 t for *B. arundinacea*.

**Growing Stock**

Growing stock is the total fresh weight of living culms in a stand. From the experimental plots it can be estimated that growing stock of *T. siamensis* is between 33.4 and 109.2 t/hectare (dependent on soil fertility). The growing stock of *B. arundinacea* is approximately 88 t/hectare.

Table 5. Bamboos harvested from natural stands and their market value. [a]

| | *B. arundinacea* | *T. siamensis* |
|---|---|---|
| **1975** | | |
| culms | 2 551 392 | 33 813 870 |
| price (Baht) | 5 | 5 |
| value (Baht) | 12 756 960 | 167 569 350 |
| **1976** | | |
| culms | 2 005 926 | 71 172 713 |
| price (Baht) | 6 | 4 |
| value (Baht) | 12 035 556 | 284 690 350 |
| **1977** | | |
| culms | 1 537 149 | 20 188 788 |
| price (Baht) | 6.5 | 3 |
| value (Baht) | 9 991 469 | 60 566 364 |
| **1978** | | |
| culms | 2 864 594 | 49 782 166 |
| price (Baht) | 6.5 | 3.5 |
| value (Baht) | 18 619 861 | 174 237 581 |

[a] Baht = U.S. $0.04930

Table 6. Exports and imports of bamboos for 1973–78.

| | Export | Import [a] |
|---|---|---|
| **1973** | | |
| culms | 8 609 513 | — |
| value (Baht) [b] | 8 482 851 | — |
| **1974** | | |
| culms | 5 321 999 | — |
| value (Baht) | 7 623 601 | — |
| **1975** | | |
| culms | 7 118 702 | — |
| value (Baht) | 7 060 071 | — |
| **1976** | | |
| culms | 1 483 704 | — |
| value (Baht) | 2 020 012 | — |
| **1977** | | |
| culms | 1 346 332 | — |
| value (Baht) | 3 605 893 | 99 563 |
| **1978** | | |
| culms | 2 726 332 | — |
| value (Baht) | 7 456 386 | — |

[a] Most of the imports were for the edible shoots from the temperate countries such as Japan, Taiwan, and China.
[b] Baht = U.S. $0.04930.

An inventory in 1979 determined the growing stock available in Kanchanaburi Province to provide raw material for a proposed pulp and paper industry. It was found that in the area of 736 $km^2$ in the north of Kanchanaburi there were six species (Table 4).

The information obtained in the inventory indicated that the amount of bamboo was enough to support a small- or intermediate-scale pulp and paper industry.

## Utilization of Bamboo Culms

Briefly, bamboo is used in paper making, fences, fishing poles, baskets, and housing. The number of culms used is estimated to be not fewer than 600 million annually.

Bamboo sprouts are an important daily food for Thai people, especially rural peoples because of the sprouts' good taste and low cost. Most bamboo sprouts consumed are from natural forests. Only a small portion comes from commercial plantations of *D. asper*. In fact, the tremendous amount of bamboo sprouts taken from natural stands is the main source of depletion. The bamboo research stations are looking for a cure for this problem.

The quantities of bamboo harvested from natural bamboo forests and the duties paid for them are substantial (Table 5); the exports of bamboos mean considerable income for the country (Table 6). Imports of bamboos have been for the edible shoots and have been primarily from Japan, China, and Taiwan.

# Malaysia

Bamboo utilization in Malaysia is widespread but mainly small scale, and the raw materials are nearly always obtained from the wild. Cultivation is seldom practiced. Due to low durability, bamboo products have a reputation for being "cheap" as compared with rattan and timber products. Research to improve the properties and usage of bamboos is in its infancy primarily because responsibility for managing bamboo resources lies with the Forestry Services who regard bamboos as weeds that interfere with timber growth and regeneration.

The bamboos of Malaysia occur gregariously, but in localized patches, on riverbanks, in disturbed lowland forests, and on hillsides, and ridge tops. Where they occur in abundance, there has been some form of disturbance of the natural forest that encourages their spread. For instance, on ridge tops, fires started by lightning sometimes have been the cause of their spread. Elsewhere, bamboos are particularly thick in areas that have had a history of shifting agriculture or wood-cutting, e.g., in the Tapah District of Perak, the Ulu Langat District of Selangor, and the Mata Ayer District of Perlis. In Sabah, the spread of the climbing bamboo *Dinochloa scandens* has been attributed to heavy logging that by canopy removal has allowed dormant bamboo seeds to germinate in profusion (218). In the Ma'okil Forest Reserve of Johore, logging is thought to have led to proliferation of bamboos as well but by tractors that have broken up and scattered clumps (Forest Department unpublished notes).

Once established, bamboo thickets are difficult to eradicate. Nearly all Malaysian bamboos are densely clumped, with the result that most culms bend outward. A few species have a sprawling, climbing habit.

Traditionally, bamboos, which are collectively known as *buloh*, have been put to many uses (59). Traditional uses are summarized in Table 1. In recent decades small-scale industries that use bamboos in the manufacture of incense sticks for Chinese religious rites have also appeared (60), especially in the Ulu Langat District of Selangor. In 1978 the Malaysian Department of Statistics recorded that Peninsular Malaysia imported M$ 146 357 (U.S. $68 378) worth of incense and exported M$ 1.4 (U.S. $654 080) million FOB (295).

In the Tapah District of Perak, very large quantities of bamboos, collected from jungles as far as 80 km away are cut into thin strips and plaited into large baskets for transporting vegetables from the vegetable production area of Cameron Highlands to the lowland cities. Such baskets are used only once and discarded upon arrival at the wholesale markets.

*Two participants from Malaysia attended the workshop and both prepared papers, which were similar in content. The text of this paper was written and presented by F.S.P. Ng (Forest Research Institute, Kepong); the tables have been taken from the work prepared by M. Noor Shamsuddin of the Faculty of Forestry, Universiti Pertanian Malaysia, Serdang.*

Table 1. Uses, local names, and location of some species in Malaysia.

| Species | Present/suggested uses | Local name | Location |
|---|---|---|---|
| *Bambusa arundinacea* | — | — | Penang, Singapore Botanic Gardens |
| *B. blumeana* | — | Buloh duri | Penang, Selangor (Kepong), Pahang (Pekan) |
| *B. burmanica* | — | Buloh aloh bukit | Kedah, Alor Star, Singapore |
| *B. glaucescens* | Picket fences, garden stakes, trellises, baskets, ornamental and hedge plants [a] | Buloh pagar | Originally from Japan and China |
| *B. heterostachya* | — | Buloh tilan/minyak/pering/pengat | Perak, N. Sembilan, Melaka, Johore, Singapore |
| *B. klossii* | — | — | Kedah, Perak (1000 m) |
| *B. magica* | — | Buloh perindu | Pahang, Cameron Highland, Selangor, Ulu Semangkok |
| *B. montana* | — | — | Penang Hill, Kedah |
| *B. pauciflora* | — | Buloh padi | Pahang, Fraser Hill |
| *B. ridleyi* | — | Buloh akar | Pahang, Singapore |
| *B. spinosa* | Building purposes, baskets, mats, hats [a] | — | — |
| *B. ventricosa* | — | — | Originally from China |
| *B. vulgaris* | Furniture, paper, pulp, shoots, landscaping [a,b] | Buloh minyak aao/aro/beting/pan | All over Malaysia |
| *B. wrayi* | — | Buloh sumpitan | Perak-Gunong Inas (1500-2000 m) |
| *Dendrocalamus asper* | Laminated trays, plywood, veneer, bridges, fences, water vessels, racks, tables, chairs, cages, fish traps, shoots [a,b] | Buloh beting | Cultivated for shoots all over; Peninsular Malaysia |
| *D. dumosus* | — | — | Kedah (Baling Hill), Langkawi |
| *D. elegans* | — | — | Kedah, Pulau Langkawi, Penang |
| *D. giganteus* | — | Buloh betong | Originally from Burma |
| *D. hirtellus* | — | Buloh kapur | Johore, Perak (Taiping), Kedah, Kelantan |
| *D. pendulus* | Basket making | — | Perak, Selangor, N. Sembilan |
| *D. sinuatus* | — | Buloh akar | Perak, N. Sembilan, Trengganu, Pahang |
| *D. strictus* | — | — | Originally from India |
| *Dinochloa scandens* | Rope making [b] | Buloh akar | Perak |
| *Gigantochloa* sp. | Structures [b] | — | — |
| *G. apus* | — | — | Selangor (Serdang), Singapore Botanic Gardens |
| *G. hasskarliana* | — | — | Penang, Singapore |
| *G. latifolia* | — | Buloh pahit | Kedah, Perak, Pahang |
| *G. levis* | — | Buloh bisa | Selangor, Melaka, Johore, Singapore |
| *G. ligulata* | — | Buloh tikus/bilalai | Perlis, Kedah, Perak, Pahang, Selangor, Kelantan |
| *G. maxima* | — | — | Selangor (Serdang) |
| var. *viridis* | — | — | Johore: Kota Tinggi |
| var. *minor* | — | — | FRI, Kepong |
| var. *ridley* | — | — | Province Wellesley, Singapore Botanic Gardens |

| | | | |
|---|---|---|---|
| *G. scortechenii* | — | Buloh semantan/ telur/rayah/Pa-aao/ gala/seremai | Kedah, Penang, Perak, Selangor, N. Sembilan, Kelantan, Pahang |
| *G. wrayi* | — | Buloh beti | Kedah, Pahang, Province Wellesley, Perak, Selangor |
| *Schizostachyum aciculare* | Handicrafts | Buloh padi/akar | Johore, Selangor, N. Sembilan, Melaka |
| *S. brachycladum* | — | Buloh nipis/lemang/ padi/urat/rusa/ pelang | Kedah, Penang, Perak, Pahang, Johore |
| *S. gracile* | — | Buloh rapen/akar | Johore: Selat Teberau, Kota Tinggi, Segamat, Sg. Sedili; Melaka: Bukit Tungal, Air Panas Selangor: Sungai Labu; Pahang: Kuala Bera, Pekan |
| *S. grande* | Rims for large baskets [b] | Buloh semeling/ semenyeh | Kedah: Grik; Perak: Cameron Highland; Pahang: Kuala Lipis, Kelantan, Selangor |
| *S. insulare* | — | — | Pulau Langkawi, Kedah, Penang, Johore |
| *S. jaculans* | Wind instruments, handicrafts [a] | Buloh sumpitan/ temiang/kerap/ tikus | Pahang, Selangor, Melaka, Johore, Singapore, Perak |
| *S. longispiculatum* | — | — | In all states except Perlis, Kedah, P. Pinang, Trengganu, Province Wellesley |
| *S. terminale* | — | — | Kedah: Inchong Estate, Sg. Kenan |
| *S. zollingeri* | Handicrafts, baskets, traps, hats, woven wares, rafts, floors, walls, partitions, cooking vessels [a] | Buloh telor/pelang nipis/dinding/kasap/ lemang/aur | Perak, Selangor, N. Sembilan, Pahang, Johore |

[a] Kiang Tao and Lin Wei-Chin (196).
[b] Holttum, R.E. (166).



Table 2. Report on revenue collected from bamboo taxation royalty and premium from 1969–77 (in M$).

| State | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|---|
| Johore | 2282.18 | 2180.42 | 3606.68 | 2947.08 | 3297.78 | 4224.60 | 3402.74 | 3768.48 | 2494.84 |
| Kedah | 29937.27 | 33795.90 | 35311.73 | 32741.84 | 37799.61 | 43918.45 | 32550.42 | 32358.06 | 37858.06 |
| Kelantan | 909.75 | 801.92 | 1100.10 | 1180.30 | 883.12 | 807.40 | 704.45 | 513.60 | 386.80 |
| N. Sembilan | 302.40 | 188.00 | 5.00 | 82.95 | 150.46 | 64.25 | 120.00 | 238.07 | 89.00 |
| Pahang | 490.49 | 280.65 | 196.66 | 159.46 | 42971.99 | 47553.01 | 18475.52 | 3347.11 | — |
| Perak | 11541.80 | 10039.12 | 10350.10 | 4735.60 | 9823.54 | 9768.40 | 13687.50 | 15572.41 | 20605.59 |
| Selangor | 7331.95 | 9367.96 | 6967.11 | 2390.82 | 3417.06 | 2604.96 | 704.70 | 2041.46 | 2517.22 |
| Trengganu | 670.37 | 447.40 | 48.65 | — | 163.95 | 131.40 | 118.80 | 716.00 | 143.60 |
| Perlis | — | — | — | — | — | — | — | — | 3055.00 |

Source: Forestry Headquarters, Kuala Lumpur.

## Problems in Utilization

Possibilities for utilization of bamboos either alone or in a supportive role for a pulp mill were investigated by McGrath (250) who found the prospects unpromising. McGrath reported that compared with conventional wood fibre, bamboo has a low productivity. Based on determinations made at the Forest Research Institute (FRI), Kepong, the moisture content of Malaysian bamboos was found to range between 46 and 58%, with 50% as an acceptable working average. On this basis, the productivity was estimated, for a dense bamboo area in Malaysia, to be not in excess of 2.5 tonnes of bone-dry fibre per hectare per year, which, assuming a yield of 40% of unbleached pulp per tonne of bone-dry wood, would give 1 tonne of pulp per hectare per year.

McGrath calculated that a mill of "minimum economic size" of 150-tonne daily capacity would have to be supplied by 50 000 hectares of dense bamboo at an annual yield of 1 t/ha. Nowhere in Peninsular Malaysia is there any dense bamboo forest of such extent. The largest area is thought to be in the northern state of Perlis, estimated at 12 000 hectares in 1970.

McGrath was also of the opinion that because bamboo forests are generally on unattractive topography, mechanical harvesting would not be possible and this in turn would make a pulp mill uneconomic. Apart from topography, the growth habits of bamboo require manual selection and harvesting, and, according to McGrath, a mill of 150-t/d capacity would require M$ 150 million (U.S.$ 70 million) and would lose M$ 50 ($23.36) per minute if supplies of raw materials were interrupted. A mill dependent on manual harvesting would in all likelihood be unable to obtain a steady supply of raw materials. The quality of bamboo-based paper was, at the same time, considered to be too low compared with what the Malaysian market has been conditioned to expect.

Problems related to the use of bamboos in other applications may be summarized briefly as:

- The clumped nature of most Malaysian bamboos results in numerous culms that are curved under tension; straight culms tend to be found only in the centre where they are not accessible;
- Owing to the initial high moisture content of bamboo, splitting occurs in drying and usage; and
- Natural durability is low because the bamboo attracts wood-boring beetles.

Traditional methods of preservation are either immersion in water until food substances contained within the culms are removed by fermentation or smoking over a fire. Neither of these processes has been adopted on a large scale.

## Bamboos in Forestry

Because bamboos have always been easily obtained from forests, very little attempt has been made to cultivate them. In fact, the forest departments, although they issue licences and collect relatively small amounts of revenue from bamboo collectors (Table 2), regard bamboos as weeds interfering with timber growth and regeneration. Physical and chemical methods of eliminating bamboo have been experimented with, and a range of control options are now available. One can starve the clumps over a period of years by breaking young culms with a kick during the growing season (251) or eliminate them with various chemical sprays (218, 398, 461).

Medway (251), a zoologist, considered bamboos to be a nuisance because they reduced the species diversity of forests by suppressing other plants and reducing the fauna to a narrow selection of bamboo-loving species.

## Taxonomy

The most important taxonomic monographs on Malayan bamboos are those by Gamble (104) and Holttum (166). Holttum recognized 7 genera and 44 species in the Malay Peninsula. Unfortunately, the work is highly technical and difficult to use.

There exists a problem of matching scientific names with local Malay names of bamboo. The Malay names tend to reflect utilization and gross morphology, e.g., *buloh betong* is the name applied to several large-stemmed species, *buloh padi* to several small-stemmed species, and *buloh akar* to all climbing species.

## Prospects for Bamboo Utilization and Research

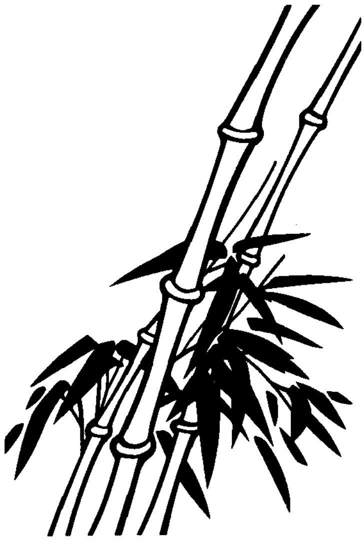
The problems involved in large-scale industrial utilization of bamboos, as described by McGrath (250), are formidable, but a pulp and paper mill is perhaps not the best destination for bamboo after all. Bamboos are, like any other natural product, best put to use in situations where their natural properties are emphasized. Among these properties are their cylindric structure, good strength-to-weight ratio, straight grain, and attractive figure. The versatility of bamboos can be improved by development of preservative treatments, by introduction of glue-lamination techniques, heat-bending, etc., and by design of suitable machinery for bamboo working.

A revival of bamboo products is possible because bamboo's greatest competitor, plastic, is becoming expensive. However, it would be a mistake to think that the clock can be turned back so easily. Traditional bamboo products lost to plastics in competition because plastic wares can be mass-produced economically without decline in quality, and new designs that look better, or different, or perform more efficiently, are introduced regularly — in other words, innovation, quality control, mass production, and attractive pricing. If these attributes could be fixed to bamboo products, one could expect bamboos to make a strong comeback. This is where research has an important role to play.

In Malaysia, interest in bamboo has been expressed by various industrial sectors as a food for canning, as an engineering material, and as a strong, lightweight pole for harvesting oil-palm fruit bunches.

Silviculturally, bamboos are attractive because, once established, they are easy to maintain. The clumps renew themselves after being cut and even if they flower, produce seeds, and die, the seeds ensure adequate regeneration.

In Malaysia, a committee to coordinate research on bamboos (and rattan) has recently been formed. It is likely to concentrate on taxonomic and ethnobotanic research and on the establishment of a living collection (arboretum) of bamboos for research, teaching, and gene-conservation purposes. The standardization of names and identities, both Malay and scientific, and the preparation of an easy guide to identification, are essential prerequisites for the industrial screening and plantation trials that are expected to be initiated shortly.



# Discussion Summary

The country reports highlight the problems of bamboo research and utilization on the regional level and indicate the importance of economic studies on the growing of bamboos. They also indicate that the interest in bamboos varies from country to country. Most of the countries attach great importance to bamboos from the point of view of both traditional and industrial uses and attach great importance to their role in the village economy and in agriculture. Management and research problems for bamboo areas exploited for traditional uses and those exploited for industrial purposes are different. The areas for traditional use are generally in the form of small holdings or individual clumps owned by individual farmers. Certain species appear to be more suitable for such purposes and need to be preferred over others. Bamboo areas for industrial purposes are generally large holdings, located in natural forests, and although the suitable and preferable species may overlap somewhat with those for traditional uses, they are primarily different. It is, however, clear from the country reports that at the moment no such distinction is drawn and the management and the use of species are mixed up. The reasons for this confusion are, first, that no utilization studies have been made and, second, that there is a general lack of information on the major silvicultural problems of bamboos, a problem spelled out in the special papers of this workshop. Although existing management methods are operating satisfactorily, studies from the point of view of maximum utilization of the resource — undertaken by an economist — are necessary. Such studies would have a great impact on the scientific and technological research needs of bamboos.

In some countries, the interest in bamboos appears to be only marginal, probably because bamboos form an integral part of the environment and the usefulness of this resource is not fully appreciated. In still other countries there appears to be a contradictory approach, namely, utilization on the one hand and eradication on the other. It is, however, not clear whether this approach is regional. Eradication is probably a reflection of the difficulty and uneconomic nature of bringing out bamboos from inaccessible areas of forests where other species are preferred. This is again a problem for the forest economist to study.

# Special Papers

# Bamboos in the Asia-Pacific Region

Y.M.L. Sharma[1]

This treatise concerns the distribution of bamboos in South and Southeast Asia and the Far East; their usefulness; phenologic characters; and factors influencing their regeneration, method of propagation, and care. Bamboo utilization has taken great strides in countries like Japan, Taiwan, China, and Indonesia and has a great future in the developing countries. Although the general belief is that bamboos are used primarily by the paper industry, nearly 80% of the bamboos produced in the Asian countries are used by the people. The consumption of bamboos for paper is negligible, but bamboos are essential to the economy of the region, and they deserve a better status than "minor forest produce" or "noncommercial species."

Bamboo-shoot farms have been extensively developed in Japan and Taiwan, and trials in similar ventures are needed in the other countries. Bamboo plantations in tropical countries are a good source for housing materials.

More than 10 million tonnes of bamboos are produced annually in the world. Almost all this comes from the East. It is estimated that in China alone there is yearly growth of 3.5 million tonnes. Eight hundred years ago Pou-Sou-Tung, a Chinese poet, wrote "A meal should have meat, but a house must have a bamboo. Without meat we become thin; without bamboo we lose serenity and culture in itself." In China bamboo is one of the four noble plants, the others being the orchid, the plum tree, and the chrysanthemum. The Vietnamese epitomize the closeness of the bamboo in their proverb "the bamboo is my brother." Bamboo is no longer called the "poor man's timber." It occupies a place of pride, being closely interwoven with the life of the people in several ways as well as with industries. It is a subject of fascinating study to the artist, poet, and the scientist. In short, bamboo finds its use from the cradle to the coffin.

Bamboo has been classified as a minor forest produce in several countries. In recent years some countries have identified it as a "nontimber" species. In view of its importance in the industrial sector and its uses in rural and urban sectors, it merits a better status in the community of forest products.

Intensive research on the different aspects of bamboo propagation and utilization is indicated, and there is a need for an international research institute on bamboo in the tropics with a chain of regional research centres and subcentres in each country.

Bamboos occur in tropical, subtropical, and temperate zones. Their genera and species are distributed widely. About 75 genera and 1250 species occur in the different countries of the world. India, Burma, Thailand, and Indonesia figure

[1]International Forestry Consultancy, Bangalore, India.

*Bambusa vulgaris in the field; the stalks are yellow.*

prominently in their bamboo resources. In Burma alone it is estimated that 4.5 million tonnes of bamboos could be available annually.

Nearly 136 species of bamboos occur in India, notables among them being *Bambusa arundinacea* and *Dendrocalamus strictus*. These occur all over the country as a component of tropical, dry and moist, deciduous forests. Northeastern India has a large number of species like *Melocanna baccifera, B. tulda, B. balcoa, Teinostachyum dulloa, Dendrocalamus brandisi,* and *D. hamiltonii*. The bamboo resources of this region have not been fully exploited due to difficulties in extraction. *Cephalostachyum pergracile, Thyrsostachys oliveri,* and *B. vulgaris* are ornamental bamboos.

Nearly 33 species of bamboos occur in Bangladesh in the North, East, and South, especially in Chittagong hill tracts. About 900 $km^2$ of reserved forests of Sylhet and Chittagong hill tracts can be classed as bamboo forests.

*Bambusa polymorpha with new vegetative shoots.*

In Burma about 90 species have been recorded, 14 of which are utilized. *Sinobambusa, Chimonobambusa, Arundinaria, Phyllostachys, Bambusa, Thyrsostachys, Gigantochloa, Dinochloa, Oxytenanthera, Dendrocalamus, Dendrochloa, Pseudostachyum, Schizostachyum, Neohouzeoua, Cephalostachyum, Melocanna,* and *Teinostachyum* are the important genera. Bamboos are found all over the country in the nine forest types either as an understory in the forest or as a pure stand. Inaccessibility, transportation, and labour problems have hampered the intensive utilization of bamboos in Burma. *M. baccifera* occurs as pure stands over 7800 km$^2$ in Arakaan Yoma.

Eleven genera and 55 species of bamboos have been reported in the Philippines under various climatic conditions. Several species of climbing bamboos form dense tangles in the forests. *B. blumeana* is the only thorny species. Bamboos confine themselves generally to marginal lands along streams, riverbanks, backyards of residences, and hillsides. They are found in Mindanao, Palawan, Kagayan, and Batan. The commonest are *B. blumeana, G. levis, B. vulgaris, D. merrillianus, S. lumampao,* and *S. lima.* Bamboos occur in malawe and dipterocarp forests more often than in any other type. Bamboo forests have been described as representative of different stages of ecologic regression, due to fires, grazing, overexploitation, etc.

Nine genera and 31 species have been reported from Indonesia. It is likely there are more. They are restricted to forest areas that have been exploited, and, other than the climbing species, they do not generally occur in rain forests. More than 90% of the bamboos come from outside the forest areas, i.e., from farm lands and homesteads. People cultivate bamboos on a large scale. *Arundinaria, Bambusa, Dendrocalamus, Gigantochloa, Melocanna, Nastus, Phyllostachys, Schizostachyum,* and *Thyrsostachys* are the important genera.

The tropical climate of Thailand is congenial to bamboos of nearly 12 genera and more than 50 species. The bamboos occur widely in the North, Northwest, and South in evergreen and deciduous forests in a contiguous belt with Burma. The commonest species in Thailand are *T. siamensis, B. blumeana, B. polymorpha, B. nana, B. tulda, D. hamiltonii, D. giganteus, D. brandisi,* and *B. arundinacea.* About 15% of the total land in Thailand, or about 77 100 $km^2$, has been reported to be under bamboo.

Japan has 13 genera and 670 species, the most important managed ones being *Phyllostachys edulis, P. reticulata,* and *P. nigra.* About 123 000 hectares of bamboo forests, of which most is privately owned and is managed by farmers, exist in Japan. Areas are set apart for culm production and (edible) shoot production separately.

Ten major genera, *Phyllostachys, Pleioblastus, Sasa, Pseudosasa,* etc. occur in Korea, all being single-stem species. About 13 species are cultivated, of which *P. reticulata* is the most important.

Twelve bamboo species, of which four are edible, have been reported in Sabah in Malaysia.

About 26 species of bamboos have been reported from Papua New Guinea. They occur extensively in the savanna of the Western Province. Many villages in the lowlands and highlands have planted the thick-walled bamboos for building and other purposes. *S. lima,* the thin-walled one, is flattened, woven into sheets, and used as cladding for walls in houses. The durability of the sheets is enhanced by impregnation with a preservative to a retention of about 8 $kg/m^3$. Dip treatment is resorted to for internally used sheets. Thick-walled *B. vulgaris* is increasingly used for furniture, novelties, decoration, artifacts, handicrafts, etc. A "bambusarium" has been established at Lae and in the Agricultural Experimental Station at Laloki (Port Moresby) with species from Southeast Asia, South and North America. Export of bamboo and bamboo articles is low.

One altitudinal variation in Bhutan has influenced the distribution of the bamboo. *D. hamiltonii* occurs in the lower regions and *B. nutans, D. sikkimensis,* and other species at higher elevations.

Four species of bamboo *Greslania* occur in New Caledonia. There are, however, many species of bamboos that have not yet been identified and listed in Southeast Asia.

The habitat of the different species of bamboos varies greatly on account of their specific habits, which are indicators of the different forest types. For example, *B. arundinacea* restricts itself to the moist and low-lying regions, banks of streams and rivers; *D. strictus,* to well-drained slopes; and *Ochlandra* species or *Oxytenanthera,* to the ridges and crests of hills in the deciduous forests of

India. In the semievergreen and evergreen forest areas of South India, the reeds come down to the sides of riverbanks. Good bamboo growth is found under a light-to-moderate canopy of deciduous species. Ecology and habitat of bamboo in the different countries offer much scope for study.

## Habit, Development, and Phenology

Bamboos are monopodial, i.e., erect as in *Melocanna* and *Phyllostachys,* sympodial or clump-forming as in *Dendrocalamus, Bambusa, Thyrsostachys,* and climbing as in *Dinochloa*. Between the single-stemmed and the densely clumped forms, there are intermediate types with somewhat open clumps (*D. membranaceus* and *Arundinaria jaunsarensis*). The erect, clump-forming species are characteristic of tropical countries. Those sending out culms singly are characteristic of subtropical or temperate regions. Bamboos vary in size from lofty forms with stems 23 m high and 23 cm thick to mere undershrubs like *Arundinaria* found at high altitudes. Species like *Dinochloa* are scandent, climbing into the crowns of tall trees.

The maximum height is reached in the first season. Soft at first, the culms become hard by deposition of silica in the walls and nodes. A sugar called *Tabashir* consisting of 80% silica with various proportions of alkalies, water, and organic matter is used for medicinal purposes and is produced from some species of bamboos. The culms are hollow with walls varying in thickness according to species; in some cases the cavities are absent, and the culms are solid. Some have prominent branches, others, only small branchlets. Some are thorny, others not.

The culms of different seasons are distinguished by the presence or absence of sheaths and changes in colour.

Bamboos flower either sporadically or gregariously. Gregarious flowering is a remarkable phenomenon occurring like clockwork. It has been recorded in India, Bangladesh, and Burma. When the bamboo gregariously flowers, the whole plant is transformed into a gigantic inflorescence. It has been attributed to several factors, chief of which is drought. Other possible causes lack evidence. Gregarious flowering is followed by death of the clump. *B. arundinacea* and *D. strictus* have gregariously flowered in India in the past as well as recently. The regeneration has not reached a stage suitable for exploitation, and the country is facing an acute shortage of bamboo for industry as well as for the people. In Bangladesh large-scale gregarious flowering has been a major setback in sustained supply of bamboos and a reason for shortage of seed for propagation. In the Philippines, work has been initiated on the causes of gregarious flowering of *S. lumampao* and *G. levis*. In a recent study, Uchimura (428) has put forth several theories about flowering of bamboos, but these need experimental proof. In Indonesia, the climate, which is equatorial with abundant moisture, may be responsible for the absence of gregarious flowering. Whereas records of stray clumps of bamboos flowering in the botanical gardens at Bogor exist, neither sporadic nor gregarious flowering has been observed in the forest areas. In Thailand, despite the occurrence of a large number of species, there is not much information on flowering and subsequent seeding. It is known that flowering and seeding does occur and that most seeds are destroyed by fire. Seeds are being collected in small quantities for experimental work at the Kanchanaburi Province research station. In Korea, recent observations indicate that *Phyllostachys reticulata* and *Pseudosasa japonica* flower abundantly every year. *Phyllostachys edulis, P. nigra,* and *Sasa koriensis* flower rarely.

The periodicity (flowering cycle) of gregarious flowering varies and is as long as 25–30 years in *D. strictus* and 40–60 years in *B. arundinacea.* In Bangladesh, it is 40–50 years in *Neohouzeoua dulloa*, 30–50 years in *Oxytenanthera nigrociliata,* 30–35 years in *M. baccifera,* 20–30 years in *B. tulda,* and 20 years in *D. longispathus*. Records of gregarious flowering exist for India, Bangladesh, and Burma, but for other countries information is wanting. Gregarious flowering and seeding results in profuse development of jungle fowl and rats. When the seed is exhausted, the rodents switch over to agricultural crops.

## Development of the Bamboos

Development of bamboos is affected by several climatic and biotic factors. For instance, adequate rainfall and the conditions of the clump have a bearing on the production of new culms. Congested clumps retard the development of new shoots, with only a few culms being produced on the periphery. If a clump is judiciously thinned, new culms are well-distributed.

Fires, grazing, shade, competition, rainfall, temperature, soil characteristics, and topographic features play an important role in bamboo growth. Fires are a menace, and the dry, dead bamboo clumps, which have produced seeds, are a serious fire hazard. In India and Bangladesh animals graze on the seedlings, and rodents cause damage to seeds and seedlings in India, Bangladesh, and Burma. In Bangladesh, bamboo is affected by fungus attack, and some interesting experiments are in progress to isolate the fungus and find appropriate control measures. Insects cause damage to living culms, both new and old, and powder-post beetles cause tremendous damage to cut culms. Shifting cultivation and improper working of clumps also lead to reduced yields of bamboo. In general, providing shade and protection from animals, fire, and unrestricted human activities would result in good growth of bamboos. Edaphic and topographic variations result in the appearance of different species of bamboo.

## Propagation of Bamboos

Natural regeneration of bamboos is either by seed or by sprouts from the rhizomes. In India, *B. arundinacea* and *D. strictus* regenerate profusely by seed after gregarious flowering, but grazing and fires damage many of the seedlings. Fencing and introducing rigid fire protection, as well as managing clumps of new bamboos, by the West Coast Paper Mills in Karnataka in India have given good results. In Bangladesh reliance has long been placed on natural regeneration. This is also the case in Burma. Work on natural regeneration of bamboo has been initiated in the Philippines, whereas natural regeneration by seed has not been reported from Indonesia. It is scanty in Thailand as seeds are reported to be destroyed by frequent ground fires. In the temperate countries of Korea and Japan, natural regeneration by seed is unreliable.

Bamboo regenerates naturally by throwing out new shoots from the rhizomes with the advent of favourable conditions early in the rains. The culms put forth their maximum height by the end of the rainy season, extending over 3–4 months. The growth is thus very fast.

Bamboos are propagated artificially by different methods, including planting seed; raising seedlings (naked or in containers); marcotting; layering;

planting rhizomes or offsets; using culm cuttings (vegetative cuttings); and planting nodal cuttings. Seeds can be sown directly in the ground in straight lines or on mounds, but they are rarely available.

Seedlings are raised in nursery beds in drills and allowed to develop for a year after which they are transplanted. An alternative is to sow seeds directly in polythene containers and to plant the seedlings with the onset of the monsoon. Sometimes, when seedlings are 7–10 cm high, they are transferred to polythene bags for further development. To utilize all the available seed, cultivators also prepare dry nursery beds in the forest and use the seedlings whenever necessary.

Marcotting involves bending a 1-year-old culm so that all the nodes are within easy reach of the workers. This is facilitated if an undercut is made at the base of the culm. The branches at the nodes are pruned to about 2.54 cm in such a way that no dormant buds are injured. An admixture of garden soil and leaf mould placed around each node is longitudinally wrapped with coconut fibre. This is then securely tied at both ends. In the Philippines, this method has produced 68.9% success in *B. blumeana*.

In layering, a 1-year-old culm is pruned without injury to the dormant buds and is half-buried in such a manner that the buds along each side of the culm are in a lateral position. About 28% success has been reported for *Bambusa* in the Philippines. Work of this nature is also in vogue at the Forest Research Institute in Bangladesh with *D. hamiltonii*.

In rhizome or offset planting, 1-year-old culm with its root system is dug up, cut to about a metre high, and planted during the rains. This method involves high costs in labour and transportation but has been successfully used for *S. lumampao*.

Culm cutting involves cutting a 1-year-old culm into two-node sections. Each cutting or section is planted obliquely with one node buried. Success rates of 60% for *B. vulgaris*, 28% for *G. aspera*, and 60% for *B. blumeana* have been reported with this method in the Philippines. Combined with treatment by hormones (indole butyric acid), this method produced 45% success in *B. blumeana*, 80% in *B. vulgaris*, and 60% in *D. merrillianus*. It is, however, opined that greater success would have resulted if the experiment had been conducted during the rains.

A nodal cutting comprises two nodes that are laid horizontally and buried level with the ground; a hole is made in the internode, which is filled with water. This method has given success in *B. vulgaris*, the dormant buds sprouting at the nodes.

India has achieved great strides in production of bamboo forests; 160 000 hectares of bamboo plantations have so far been raised in the different states. Bamboo is also being cultivated by villagers all over India in homesteads and village wastelands. Vegetative propagation by rhizomes and offsets is an age-old method and has been adopted by villagers in India, Bangladesh, and Burma. Large numbers of bamboo clumps are planted in village groves in Bangladesh every year. Planting is done by individuals in their backyards or on vacant areas in the villages. Organized and managed plantations do not exist. Though about 10–12 species are cultivated, the commonest are *B. vulgaris* and *B. nutans* because planting material for these two species is readily available. Plantations of bamboo have not been attempted so far in Burma except on an experimental scale. *D. longispathus*, *B. vulgaris*, *D. calostachyus*, *D. giganteus*, and *T. siamensis* are planted and used for domestic purposes by villagers. In the Philippines, villagers plant bamboos to cater to their individual requirements and local trade. The methods used are rhizome planting, marcotting, and offset planting. Rhizome planting or planting culm cuttings is practiced by villagers in Indonesia. In fact, nearly 13 species are cultivated in Java and are frequently grown with horticultural crops. Cultivation and use of bamboos have been closely linked to the life of the rural community. More than 95% of the bamboo used in Indonesia comes from farmlands and homesteads. *B. arundinacea, G. atter, G. apus*, and *G. verticillata* are the most important ones. In Korea propagation of bamboos is carried out by villagers who mainly use rhizome cuttings. Trials are also in progress to propagate bamboos by seed and seedlings. Normally about 1000 rhizome cuttings of mother bamboos are planted per hectare and manured when necessary; they will form a dense stand in 5 years. In Thailand vegetative methods like rhizome planting or planting of stem cuttings are in vogue. One of the species largely cultivated is *D. asper* for its shoots and windbreaks. In Japan, the cultivation of bamboo by rhizome cuttings has been perfected. Also, intensive work has been done in various parts of China on cultivation and management of bamboo. Much work has been done on *Phyllostachys pubescens*.

### Economics of Bamboo Plantations

Bamboo plantations raised artificially solely for pulp and paper would not be profitable, as the mills generally pay a royalty far lower than the cost of raising the plantation. But bamboos raised to meet the needs of rural peoples pay good dividends as long as they are sold by the number of culms. In other words, where large-scale plantations are raised for the pulp industry, a certain proportion of culms should be earmarked for sale to the public. Only then would the proposition be profitable. Bamboos can also be grown with species like *Eucalyptus citriodora*, the yield being both pulpwood and foliage for distillation and production of oil. One plant can be allowed to grow, and the rest pollarded and the leaves distilled for the oil. The oil is now valued at about U.S. $10–11/kg, and a hectare could yield 2–4 kg of oil. The working expenses would not exceed U.S. $2. The distillation could be continued until the bamboos are ready for harvest; thus the cost of bamboos could be recovered.

## Care, Management, and Disposal

Bamboo areas should be rigidly protected from fire and grazing animals. About 3–4 weedings around planted seedlings, hoeing around plants, earthing up, and mulching are done during the first 2 years. In areas of low rainfall, bamboos are planted in sunken pits specially designed for moisture conservation in India. The use of fertilizers in artificial regeneration of bamboo — about 56 g of NPK in two split doses — would boost growth. In the case of larger seedlings, the dosage of fertilizer could be more. Intensive treatment is meted out for *Phyllostachys edulis* in Japan, Korea, and Taiwan where bamboo is grown for shoots. Irrigation speeds up the growth of seedlings.

Bamboo forests in India, Bangladesh, and Burma are generally managed according to a "culm-selection method." The dead, dying, and oldest culms are thinned out, care being taken so that one or two mature culms are retained adjacent to the new culms to give stability. A bamboo clump has to be intensively worked if new shoots are to be obtained and to be distributed in the clump properly. Congested clumps, which pose many problems, result from damage by grazing animals, insects, fire, and improper management. To reorient congested clumps, labourers cut tunnels at right angles through the clump and the culms are clear-felled. The culms in the four segments are then thinned. Alternatively, culms in a clump are clear-felled in the form of a horseshoe; those remaining are thinned. Complete clear-felling of culms or clumps is not advocated, as it results in switchy shoots and losses.

The bamboo areas are usually divided into sections, and felling is rotated so that a section is cut and is left for 2, 3, or 4 years, depending on the felling cycle. In some cases, the felling cycle is as high as 6–10 years in Burma. Most countries have proper felling rules that stipulate the number of old culms to be retained in the clump.

In the thorny varieties like *B. arundinacea* and *B. blumeana*, people tend to extract only the top portions of the culms because of the difficulty in clearing the interlacing thorny branches at the bottom. However, industries first clear the base of the clumps and then extract the culms on a culm-selection basis.

The management practices, especially the felling cycle of 3 years or more, were introduced when bamboo was considered for supply to industries. In countries like India and Bangladesh, where the demand for bamboo is heavy for uses other than traditional ones, e.g., basket weaving, the authorities may have to shorten the felling cycle to maintain quick and sustained supplies to the community. Intensive management would be needed as would experimental data.

In Indonesia, the management practice has been to restrict the removal of the most mature culms from the clumps only when the need arises, but, to date, the bamboos for supply to paper mills have been clear-felled and poorly managed — a fact that has adversely affected further development of clumps in Banyuwangi and South Sulawesi. In many cases the villagers cut the periphery of the clump — a procedure that stops the outward development of rhizomes and prompts new culms to appear in the interior of the clump and to create congestion in the clump and malformation. The management of bamboo in Thailand also has yet to be scientifically oriented. The present felling cycle is 1 year, but there is some move toward adoption of a 3-year felling cycle. No felling rules are enforced; most mature culms are cut and extracted. Other than the bamboos growing in the Reserved Forest, bamboos are not protected, and extraction is not supervised by any authority. Thus bamboo is extracted freely at present, and there are no records to indicate the actual quantity extracted. In Japan where bamboos are managed for culms, rules are strict; fellings are selective, carried out during autumn. The cutting cycle varies from 3 to 5 years for *P. reticulata* and 5–10 years for *P. edulis* when green culms show signs of deterioration.

The general experience in India is that the average yield per hectare from natural forests of bamboo varies from 2.5 to 4.0 tonnes/hectare. From artificially propagated forests one can expect about 6–7.5 tonnes/hectare if the crop is managed properly.

To harvest bamboos, people usually obtain permits, licences, or leases. The period may extend from a few days to years. Tribes and people living in forests are permitted to take their bamboo needs free from forests under government control. Disposal of bamboos by permits or short leases (1–2 years) is detrimental to the crop, because the purchaser has no interest in its improvement. The impact of poor control of harvesting is worst in countries where bamboos are in short supply due to gregarious flowering and seeding and subsequent death of the clumps. In India, states like Karnataka departmentally extract bamboos and distribute them to consumers through forest depots. Consumers are charged a royalty plus extraction and supervision charges. This practice has prevented indiscriminate exploitation of the bamboo.

Where bamboos are conceded on long leases, say 10–25 years, to an industry such as pulp and paper on a royalty basis, the maintenance of the bamboo areas is better because it is in the interest of the consumer. The West Coast Paper Mills in India have their own forestry department. They have fenced the leased bamboo areas, spaced out the natural regeneration of *D. strictus*, and reforested the gaps by artificial planting with the larger species of bamboo *Bambusa arundinacea*. They have also initiated raising of about 200 hectares of plantations of different species on a leased area. Other mills are also thinking of resorting to these practices. Fertilization with NPK, soil working, and moisture-conservation techniques are adopted to further the bamboo's growth. Bamboos are also leased to the paper industries in Bangladesh on a royalty basis. About 3.3 million tonnes (air-dried) bamboos are consumed for domestic purposes in Burma. There are at present only two paper mills in Burma, but one more has been proposed in Arakaan. In Henzada/Bassein areas a rayon mill is expected to be installed. With poor utilization, bamboo stands require better management. In forests other than reserves in Burma, bamboo harvesting for personal use is free of royalty to villagers, as bamboo is an essential commodity in rural communities. In the Philippines, though several bamboo species are considered suitable for paper, the paper mills are not using any bamboos due to scarcity. The disposal of bamboos by the forest department is done through permits of 10 pesos each (peso = U.S. $0.1380) and payment of one-tenth of the market value of the bamboos.

In Indonesia, people cut bamboos and transport them in carts or trucks to selling centres. The price of a culm varies from 150–300 rupiahs (rupiah = U.S. $ 0.0016) in rural areas to 500 rupiahs in urban areas. There appears to be a demand to the tune of at least 600 million pieces of bamboos or 3.3 million tonnes annually. Nearly 30% of the bamboos produced are consumed for housing and other needs like basket making; the rest finds its way to the cottage industries. The new shoots of many species of bamboos, notably *D. asper*, are consumed as food.

In Thailand, the disposal of bamboos to the public and to the paper mills in Kanchanaburi Province, the only area using bamboos for paper, is free of royalty. People are allowed to extract bamboos as and when needed from forests. The question of levying a royalty on bamboo is engaging the attention of the Royal Forest Department. Without such a royalty, there is danger of depletion of bamboo resources. It is all the more important in view of large-scale clearance of bamboos by people shifting cultivation in the hill areas.

In Korea, Japan, and Taiwan, bamboos are disposed of as and when they mature. In Japan, normally bamboo forests contain 6000–7000 culms per hectare, and each year about 1000 culms are harvested.

## Bamboo Utilization

The bamboos are used for sprayers, ropes, tholepins, masts, sails, net floats, basket fish traps, awnings, food baskets, beds, blinds, bottles, bridges, brooms, food, lanterns, umbrella handles, fans, brushes, chains, chopsticks, combs, drogues, dustpans, paper, pens, nails, pillows, tobacco and hookah pipes, anchors, fishing nets, fishing rods, flagpoles, hats, ladles, lamps, musical instruments, mats, tubs, caulking materials, scoops, shoes, stools, tables, tallies, traps, joss sticks, back scratchers, walls, buildings, walking sticks, lance staves, thatching and roofing, loading vessels, trays, bows and arrows, water and milk vessels (*chungas*), hedges, furniture, agricultural implements, fodder, fuel, floats for timber, trellises, flues, handicrafts, sledges, toys, pipes, cooking utensils, tool handles, polo mallets, stabilizers for haystacks, coffins, cart yokes, scaffolding, ladders, containers, stakes, tiles, seed drills, slats, ornamentals, cordage, wrappers, shuttles and afforestation.

In India, bamboos are used for a variety of purposes by people. Nearly 80 paper mills depend wholly or partly on bamboos, as they are the only long-fibred resource easily available in the country and extraction of conifers from the Himalayas is expensive. They are also used in rural and urban sectors, agricultural and horticultural pursuits, and control of soil erosion. Utilization practices, however, are wasteful; when the bamboo is extracted, only a small fraction of its biomass, i.e., the usable portion of the culm, is taken out, and the rest is allowed to go to waste in the forest. In contrast, in countries like Japan, even the twigs and branches are converted into brooms and exported. In Bangladesh, bamboos play a vital role in the rural economy; one wonders at the innumerable uses to which bamboos are put in this country. It is, therefore, imperative for the country to encourage the production of bamboos more in homesteads and the rural sector. In Burma, the industrial utilization of bamboos is 17% of the total production; the remainder is consumed locally for rural and urban needs. There are only two paper mills, using resources from the Pegu Yoma region. A proposal has been to establish another mill to utilize *Melocanna* and other bamboos and hardwoods to the Arakaan Division. Also, a rayon pulp plant is being considered in the Henzada/Bassein Forest Division.

In the Philippines nearly 80% of the bamboos are used for construction and for rural endeavours. There is great demand for bamboos in the cottage industry. The handicraft work has been developed with assistance from technicians from Japan. Bamboos are used in the banana industry for props as protection against wind damage. The people are aware of their personal needs and most raise bamboos. The total area under bamboo in the Philippines is reported to be 7924 hectares, which is 0.03% of the total land area. There is thus a case for increased cultivation to meet internal needs as well as to combat soil erosion. In Indonesia, bamboos are the lifeblood of the people. Some villages raise pure bamboo forests and use them for houses and for many other purposes. In Thailand the bamboos are extensively used in the rural sector, and fishing rods of *Thyrsostachys siamensis* are exported on a large scale. Also, there is a great future for export of bamboo shoots of *Dendrocalamus asper*.

**Bamboo Shoots and Shoot Farms**

The succulent shoots of bamboos are highly nutritious and palatable. In India, Bangladesh, and Burma, bamboo shoots are used for pickles and in curries only to a limited scale subject to availability. The removal of new bamboo shoots from reserved forest areas is discouraged as it would impede regeneration of bamboos. No forest areas have been earmarked for bamboo shoots. In Thailand, bamboo shoots are consumed in fresh, pickled, and dried forms. Most of the species growing in Thailand produce edible shoots, but the best ones are those of *Dendrocalamus asper, Thyrsostachys siamensis, D. giganteus, D. merrillianus*, and *Gigantochloa albociliata*. Leaves of *Tiliocosa racemosa* (*Menispermaceae*) are added during cooking. Shoots of *D. giganteus* can be eaten raw. Shoots of *D. asper* are exported. In the Philippines, edible bamboos are cultivated at Panabo, Davao del Norte.

In Taiwan, management of *Phyllostachys edulis* and *Dendrocalamus latiflorus* has reached a high degree of specialization, including processing, canning, and export. During 1977, Taiwan exported nearly U.S. $25 million worth of bamboo shoots. About U.S. $40.8 million worth of bamboo products were exported, exports doubling in the past 4 years. In Japan, 8000 tonnes or more of bamboo shoots are consumed per year, and about the same weight is consumed in Taiwan, even though the population is only one-sixth that of Japan.

In the case of *Phyllostachys* managed for shoots in Japan, the crop is spaced out. The tops are pollarded at 30–40 feet (9–12 m) so that sunlight and warmth prevent snow damage. A temperature of at least 20 °C is needed for shoot production. Shoots are produced in April–May and November. The yield of edible shoots is about 10 tonnes per hectare, valued at about a million yen (yen = U.S. $0.00455), the expenditure being one-tenth to one-third the return, depending on how well the farmer has maintained the area and whether family members or hired hands do the work. The management of bamboo for soft, good-quality shoots involves yearly soil dressing, application of straw litter and farmyard manure.

In Korea, edible shoots are collected when they are about 4–7 cm. From an intensively managed area, it is possible to collect about 10 000 kg shoots per hectare. The average price of shoots is 280 won/kg (won = U.S. $0.001671). Harvesting is only once a year, April–mid-May. Vigorous shoots are retained for later use as mother bamboo. Research on the taste of the shoots is carried out.

Only four edible species of bamboos occur in Malaysia, but bamboo is used in delicate curios, boards, flooring tiles, etc. Such items are also manufactured in Japan and Taiwan and are exported. The treatment of *Phyllostachys edulis* with creosote in Taiwan and supply of treated bamboos for banana props for both internal and external consumption have helped the banana industry. Treated bamboos could also be used for building or cheap houses in rural areas. Short bamboo pieces (about 1 m) treated with creosote are used for oyster cultivation in Taiwan. In Thailand more than 1 million hectares of bamboo resources exist for pulp making, small-scale industries, handicrafts, and conservation of soil. The proper utilization of these resources would greatly benefit the masses. In India, Bangladesh, and Burma, where gregarious flowering of bamboos has occurred, the large quantities of seed were used as food by many people. The grain is powdered into flour and consumed alone or with wheat flour. The dead bamboo has been used by the paper industry.

Bamboo is commonly used in construction. Better-quality bamboos are used for house posts. Smaller and thinner ones are used for roof frames to support country tiles. Split and plaited bamboo sheets are used for walls, ceilings, and roofs. Small, round, pliable bamboos are used for fishing rods, frames for fishing nets, walking sticks, handles of tools, musical instruments, and larger varieties are used for watercraft, bullock carts, and containers. The containers are sometimes dyed, painted, and sold as curios in urban areas. Because it is lightweight, strong, and cheap, bamboo has proved to be useful in rural, urban, and industrial sectors of many countries (Table 1).

## Rehabilitation of Bamboo-Seeded Areas

A scheme for rehabilitation of areas where bamboo had flowered gregariously between 1960 and 1965 (*B. arundinacea* and *D. strictus*) was implemented in India. The dead bamboo clumps were all clear-felled and supplied to paper and rayon industries. The areas were burned and were planted with teak stumps and eucalyptus. Sowings of *Eucalyptus citriodora* seed in the burned patches gave excellent results.

Table I. Consumption (%) of bamboos in the Asia-Pacific Region by end-use and a breakdown of the uses by species (country codes in the breakdown are India, In: Bangladesh, Ba; Burma, Bu; Philippines, Ph; Indonesia, Ind; Thailand, Th; Japan, Ja; Taiwan, Tai; Korea, Ko).

| Country | Construction | | Rural uses | Packaging | Pulp manufacture | Other uses |
|---|---|---|---|---|---|---|
| | Housing | Others | | | | |
| Bangladesh | 50 | 10 | 20 | 5 | 10 | 5 |
| Burma | 33 | 32 | 32 | 5 | – | 1 |
| India | 16 | 16 | 30 | 7 | 17 | 14 |
| Japan | 24 | 7 | 18 | 7 | 4 | 41 |
| Philippines | 80 | – | 15 | 2 | – | 3 |
| Thailand | 33 | 20 | 6 | – | 8 | 33 |

**Walling of native huts**
*Bambusa tulda* (Bu, Ba, Ind)
*B. polymorpha* (Bu)
*B. blumeana* (Ph)
*B. atra* (Ind)
*Dendrocalamus asper* (Ind)
*Gigantochloa nigrociliata* (Ind)
*Melocanna baccifera* (Ba)
*Neohouzeoua dulloa* (Bu, Ba)
*Sinobambusa elegans* (In)
*Schizostachyum lumampao* (Ph)
*Thyrsostachys siamensis* (Ph)
*T. oliveri* (Th)

**Lance staves**
*Bambusa blumeana* (Ph)
*Dendrocalamus strictus* (In, Bu)
*Ochlandra travancorica* (In)
*O. scriptorica* (In)
*Schizostachyum lima* (Ind)
*Thyrsostachys siamensis* (Th)
*T. oliveri* (Th)

**Thatching and roofing**
*Bambusa arundinacea* (In, Ba, Bu, Ind)
*B. tulda* (In, Ba, Bu)
*B. vulgaris* (Ind)
*B. blumeana* (Ph)
*B. polymorpha* (In, Bu, Ba)
*Dendrocalamus strictus* (In, Ind)
*D. longispathus* (Ba, Bu)
*D. membranaceus*
*D. brandisi*
*D. hamiltonii*
*Gigantochloa atter* (Ind)
*Chimonobambusa falcata* (In)
*Melocanna baccifera* (Ba, Bu)
*Neohouzeoua dulloa* (Ba, Bu)
*Oxytenanthera monodelpha* (In)
*Schizostachyum brachycladum* (Ind)

**Tea estates**
*Pseudostachyum polymorphum* (In)

**Constructions**
*Bambusa polymorpha* (In, Ba, Bu, Ind, Th)
*B. balcoa* (In)
*B. tulda* (In, Ba, Bu, Ind)
*B. arundinacea* (In, Ba, Ind, Th)
*B. nutans* (In, Bu, Th)
*B. khasiana* (In)
*B. vulgaris* (In, Ba, Ph, Ind)
*B. burmanica* (Ba)
*B. pallida* (Bu)
*B. blumeana* (Ph, In)
*B. atra* (Ind)
*Cephalostachyum pergracile* (In, Ba, Bu)
*Dendrocalamus membranaceus* (In, Ba, Bu)
*D. hamiltonii* (In, Ba, Th, Bu)
*D. giganteus* (In, Ba, Ind, Bu)
*D. longispathus* (In, Ba, Th)
*D. strictus* (In, Bu)
*D. calostachyus* (Bu)
*D. merrillianus* (Ph)
*D. asper* (Ind)
*Gigantochloa nigrociliata* (In, Ind)
*G. verticillata* (Bu, Ind)
*G. levis* (Ph)
*Melocanna baccifera* (In, Ba, Bu)
*Neohouzeoua dulloa* (In, Bu)
*Oxytenanthera nigrociliata* (Ba, Bu)
*Schizostachyum lumampao* (Ph)
*S. brachycladum* (Ind)
*S. lima* (Ind)
*Teinostachyum beddomei* (In)
*Thyrsostachys oliveri*
*Phyllostachys* sp. (Ja, Tai, Ko)

**Walking sticks**
*Arundinaria armata* (In)
*Dendrocalamus strictus* (In, Bu)
*Oxytenanthera nigrociliata* (Ba, Bu)
*Phyllostachys manni*

*(continued)*

*(Table 1 continued)*

**Basket making**
*Arundinaria intermedia* (In)
*Bambusa nutans* (In, Bu)
*B. pallida* (In, Th)
*B. khasiana* (In)
*B. arundinacea* (In, Bu, Ind, Th)
*B. tulda* (Ba, Bu, Ind, Th)
*B. vulgaris* (Ba, Bu, Ph, Ind)
*B. villulosa* (Bu)
*B. flexuosa* (Th)
*B. polymorpha* (Ba, Ind, Th)
*B. blumeana* (Ph, Ind)
*Chimonobambusa falcata* (In)
*Cephalostachyum pergracile* (Ba, Bu)
*Dendrocalamus hamiltonii* (In, Bu)
*D. longispathus* (In, Ba, Bu, Th)
*D. strictus* (In, Bu)
*D. giganteus* (In, Ba, Ind)
*D. merrillianus* (Ph)
*D. asper* (Ind, Th)
*Dinochloa compactiflorus* (Bu)
*Gigantochloa nigrociliata* (In, Bu)
*G. macrostachya* (Bu)
*Indocalamus wightiana* (In)
*Melocanna baccifera* (Ba, Bu)
*Neohouzeoua helferi* (In)
*N. dulloa* (Bu)
*Oxytenanthera ritcheyi* (In)
*O. nigrociliata* (Ba, Bu)
*O. monostigma* (Bu)
*Pseudostachyum polymorphum* (Bu)
*Schizostachyum diffusum* (Ph)
*S. lumampao* (Ph)
*Thamnocalamus spathiflora* (In)
*Teinostachyum helferi* (Bu)
*T. griffithii* (Bu)
*Phyllostachys* sp. (Ja, Ko, Tai)
**Loading vessels**
*Neohouzeoua dulloa* (In)
*Teinostachyum* dulloa
**Bows and arrows**
*Bambusa flexuosa* (Th)
*B. arundinacea* (In)
*Cephalostachyum capittatum* (In)
*C. pergracile*
*Dendrocalamus strictus* (In)
*Schizostachyum rogersii* (Bu)
*S. lima* (Ind)
**Cooking utensils**
*Bambusa arundinacea* (Ind, Ba, Bu, Th)
*B. blumeana* (Ph)
*Cephalostachyum pergracile* (In, Ba, Bu, Th)
*Gigantochloa atter* (Ind)
*Neohouzeoua dulloa*
*Schizostachyum zollingeri*

**Mats**
*Arundinaria intermedia* (In)
*Bambusa nutans* (In, Bu)
*B. teres* (In, Bu)
*B. tulda* (In, Ba, Bu, Ind, Th)
*B. pallida* (In, Ba, Th)
*B. arundinacea* (In, Ba, Bu, Ind, Th)
*B. blumeana* (Ph, In)
*Cephalostachyum pergracile* (In, Ba, Bu)
*Dendrocalamus strictus* (In)
*D. hamiltonii* (In, Ba, Bu, Th)
*D. merrillianus* (Ph)
*D. membranaceus* (Th)
*D. brandisi* (Th)
*Dinochloa distans* (Bu)
*Gigantochloa levis* (Ph)
*G. atter* (Ind)
*G. macrostachya* (Bu)
*G. apus* (Ind)
*Indocalamus wightiana* (In)
*Melocanna baccifera* (Ba)
*Pseudostachyum polymorphum* (Bu)
*Schizostachyum lumampao* (Ph)
*Teinostachyum dulloa* (In, Bu)
*Thyrsostachys siamensis* (Th)
**Water and milk vessels (*Chunga*); water buckets; cups; containers**
*Bambusa pallida* (In, Ba)
*B. tulda* (Ba, Bu)
*B. blumeana* (Ph)
*Dendrocalamus sikkimensis* (In)
*D. giganteus* (In, Ba, Bu, Ind, Th)
*D. hookeri* (In, Bu)
*D. brandisi* (Bu)
*D. asper* (Ind)
*D. hamiltonii* (Th)
*Gigantochloa levis* (Ph)
*G. asper* (Ph)
*Melocanna baccifera* (Ba, Bu)
**Hedges**
*Bambusa nana* (In, Ba, Bu, Th)
*B. vulgaris* (Ba, Ind)
*B. balcoa* (Ba, Ind)
*B. arundinacea* (Bu)
*Cephalostachyum pergracile* (Bu)
*Cephalostachyum burmanicum* (Bu)
*Dendrocalamus giganteus* (In, Ba, Bu, Ind, Th)
*Gigantochloa atter* (Ind)
*G. nigrociliata* (Ind)
*Oxytenanthera nigrociliata* (Ba)
*Thyrsostachys siamensis*
**Fuel**
All bamboos and rhizomes of bamboos (In, Ba, Bu, Ind)

*(continued)*

**Seed food**
*Bambusa arundinacea* (In, Ba, Bu)
*Cephalostachyum pergracile* (In, Ba, Bu)
*Dendrocalamus strictus* (In)
*Dinochloa compactiflora* (Bu)
*Melocanna baccifera* (Ba, Bu)
*Thyrsostachys oliveri* (Ba, Bu)

**Furniture**
*Bambusa tulda* (Ba, Bu)
*B. glaucescens* (Ind)
*B. vulgaris* (Ind)
*B. arundinacea* (Th)
*Dendrocalamus strictus* (In, Ba, Bu)
*D. membranaceus* (Th)
*D. brandisi* (Th)
*D. latiflorus*
*D. longispathus* (Th)
*D. asper* (Th)
*Gigantochloa atter* (Ind)
*G. apus* (Ind)
*Melocanna baccifera* (Ba, Bu)
*Schizostachyum diffusum* (Ph)
*Thyrosostachys siamensis* (Ind, Th)
All thick-walled species (Ph, Ind)
*Phyllostachys* sp. (Ja, Ko, Tai)

**Agricultural implements**
*Bambusa vulgaris* (Ba, Bu, Ind, Ph)
*B. balcoa* (Ba, Bu, Ind)
*B. blumeana* (Ph, Th)
*B. flexuosa* (Th)
*Dendrocalamus strictus* (In, Bu, Th)
*D. merrillianus* (Ph)
*D. asper* (Th)
*Ochlandra travancorica* (In)
*Thyrsostachys siamensis* (Th)
*T. oliveri* (Th)
All thinner varieties (In, Ba, Bu)

**Fodder**
*Arundinaria racemosa* (In)
*Chimonobambusa densifolia* (In)
*Cephalostachyum pergracile* (In)
*Dendrocalamus strictus* (In)
*D. sikkimensis* (In)
Leaves of all bamboos (Ba, Bu, Ind)

**Floats for timber; rafts**
*Bambusa arundinacea* (In, Bu, Th)
*B. blumeana* (Ph, Ind)
*Dendrocalamus hamiltonii* (In, Bu)
*D. longispathus* (Ba)
*D. distans*
*D. asper* (Ind)
*D. membranaceus* (Th)
*Ochlandra seriptoria* (In)
*Melocanna baccifera* (Ba, Bu)
*M. compactiflorus* (Th)
*Neohouzeoua dulloa* (Ba)

**Tool handles**
*Bambusa blumeana* (Ph, Th)
*B. flexuosa* (Th)
*B. polymorpha* (Ba, Bu, Ind)
*Dendrocalamus asper*
*D. strictus* (In, Th)
*D. merrillianus* (Ph)
*Ochlandra travancorica* (In)
*Teinostachyum griffithii* (Ba, Bu)
*Thyrsostachys siamensis* (Th)
Solid varieties (Ind)

**Fencing**
*Indocalamus wightianus* (In, Ba, Bu, Ind, Ph, Th)
All bamboos (In, Ph, Ba, Bu, Ind, Th, Ja, Ko, Tai)

**Hookah pipes**
*Chimonobambusa falcata* (In)
*Phyllostachys sedan* (Bu)
*Thamnocalamus spathiflora* (In)
*T. aristatus*
*Teinostachyum griffithii*

**Fishing rods**
*Arundinaria amabilis* (In)
*Bambusa glaucescens* (Ind)
*B. atra* (Ind)
*Chimonobambusa falcata* (In)
*C. khasiana* (In)
*C. intermedia* (In)
*Dendrocalamus strictus* (In)
*Schizostachyum zollingeri* (Ind)
*S. blumei* (Ind)
*S. lima* (Ph)
*Thyrsostachys siamensis* (Th, Ind)
*T. oliveri* (Th)
*Phyllostachys nigra* (Ja)

**Shoots for food**
*Bambusa tulda* (In, Ba, Bu, Ph, Ind)
*B. arundinacea* (In, Ba, Bu, Ind)
*B. nana (Bu)*
*B. vulgaris* (Bu, Ph, Ind)
*B. blumeana* (Ph)
*B. glaucescens* (Ind)
*Dendrocalamus hamiltonii* (Ba, Bu)
*D. latiflorus* (Tai)
*D. giganteus* (In, Ind)
*D. longispathus* (Ba)
*D. flagellifer* (Bu)
*D. merrillianus* (Ph)
*D. asper* (Ind, Th)
*Dinochloa scandens* (Ind)
*Gigantochloa nigrociliata* (Ind)
*G. hasskarliana* (Ind)
*G. verticillata* (Bu, Ind)
*G. levis* (Ph)

*(continued)*

*G. atter* (Ind)
*G. albociliata* (Th)
*Phyllostachys edulis* (Ta, Ja, Ko)
*Schizostachyum brachycladum* (Ind)
*S. blumei* (Ind)
*S. zollingeri* (Ind)
*Sinobambusa elegans* (In)
*Thyrsostachys siamensis* (Th)
All large bamboos — shoots (Th)

**General utility**
*Bambusa arundinacea* (In, Ba, Bu)
*B. tulda* (Bu)
*B. pallida* (Bu)
*B. blumeana* (Ph)
*B. vulgaris* (Ph)
*Cephalostachyum pergracile*
*C. burmanicum*
*Dendrocalamus strictus* (In, Bu)
*D. hookeri* (In, Bu)
*D. hamiltonii* (Ba)
*D. calostachyus* (Bu)
*D. merrillianus* (Ph)
*Dinochloa* sp. (Ph)
*Gigantochloa levis* (Ph)
*G. asper* (Ph)
*Neohouzeoua dulloa*
All strong bamboos (Ind, Th, Ja, Ko, Tai)

**Punting poles**
*Oxytenanthera stocksii* (In)
Solid varieties (Ba, Bu)
*Phyllostachys nigra* (Ja)

**Sericultural industry — trays for silkworms**
*Bambusa arundinacea* (In)
*Dendrocalamus strictus* (In)
*Thyrsostachys siamensis* (Th)
All bamboos (Ba, Ind)

**Chicks for doors and windows**
*Bambusa arundinacea* (In, Bu, Ind, Th)
*B. polymorpha* (Ba, Bu)
*B. blumeana* (Ph, Ind)
*B. vulgaris* (Ind)
*Dendrocalamus strictus* (In)
*D. longispathus* (Th)
*D. membranaceus* (Th)
*Melocanna bambusoides*
*Neohouzeoua dulloa* (Ba, Bu)
*Schizostachyum lumampao* (Ph)
*S. zollingeri* (Ind)
*Thyrsostachys siamensis* (Th)
*T. oliveri* (Th)
All bamboos (Ja, Ko, Tai)

**Pipes**
*Bambusa arundinacea* (Bu)
*Neohouzeoua dulloa* (Bu)
*Teinostachyum griffithii* (In, Ba)

**Haystack stabilizers**
*Bambusa vulgaris* (Ba, Bu)
*B. tulda* (Ba, Bu)
*B. blumeana* (Ph)
*Dendrocalamus strictus* (In)
All bamboos can be used (Ind)

**Horticultural pursuits**
*Bambusa arundinacea* (In, Bu)
*B. polymorpha* (Ba)
*B. blumeana* (Ph)
*Dendrocalamus strictus* (In)
*Melocanna baccifera* (Ba, Bu)
All bamboos (Ind, Th)
Other strong species (Ph)

**Cremation; coffins**
*Bambusa arundinacea* (In)
*Dendrocalamus strictus* (In)
All bamboos

**Cradles**
*Bambusa arundinacea* (In)
*Dendrocalamus strictus* (In)

**Scaffolding**
*Bambusa arundinacea* (In)
*Dendrocalamus strictus* (In)

**Cart yokes**
All large-sized, hard and solid bamboos (In)

**Ladders**
*Bambusa arundinacea* (In)
*Dendrocalamus strictus* (In)

**Musical instruments (flutes; marimba; horns; clarinets; flageolets; saxophones; piccolos; drums; etc.)**
*Arundinaria* sp.
*Arundinaria mitskayamensis* (Ph)
*Dendrocalamus strictus* (In, Th)
*D. longispathus* (Th)
*Gigantochloa atter* (Ind)
*Schizostachyum lima* (Ind)
*S. blumei* (Ind)
All small-sized bamboos (Ph)

**Containers for cleaning grains**
All bamboos (In)

**Protection during grain pounding**
*Bambusa arundinacea*
All large-sized bamboos (In)

**Cart sheds; roofs**
*Bambusa blumeana* (Ph)
*Dendrocalamus merrillianus* (Ph)
All bamboos (In)

**Stakes for foresters**
*Thyrsostachys siamensis* (Th)
*T. oliveri* (Th)
All bamboos (In)

*(continued)*

*(Table 1 continued)*

**Country tiles**
*Bambusa arundinacea* (In)
**Pan trays**
*Neohouzeoua dulloa* (In)
*Teinostachyum dulloa* (Bu)
**Seed drills**
*Dendrocalamus strictus*
**Containers to administer medicine to animals**
*Bambusa arundinacea* (In)
**Fishing implements; floats; pens; traps**
*Bambusa polymorpha* (Ba, Bu, Ind)
*B. atra* (Ind)
*B. vulgaris* (Ba, Bu)
*B. blumeana* (Ph)
*Gigantochloa levis* (Ph)
*Melocanna baccifera* (Ba, Bu)
*Neohouzeoua dulloa* (Ba, Bu)
*Schizostachyum blumeana* (Ind)
*S. lumampao* (Ph)
**Boat roofs**
*Bambusa arundinacea* (In)
*B. tulda* (Ba, Bu)
*B. blumeana* (Ph)
*Melocanna baccifera* (Ba, Bu)
**Ornaments**
*Bambusa vulgaris* (Ind, Ba, Bu, In, Ph)
*B. nana* (Ph)
*B. vulgaris* var. *striata* (Ph)
*B. glaucescens* (Ph)
*B. polymorpha* (Ind)
*B. atra* (Ind)
*Cephalostachyum pergracile* (In)
*Dendrocalamus giganteus*
*Phyllostachys aurea* (Ind)
*Schizostachyum brachycladum* (Ind)
*S. zollingeri* (Ind)
*Thyrsostachys siamensis*
**Culm sheaths (irrigation)**
*Bambusa blumeana* (Ph)
Climbing species of bamboos (Ph)
*Dendrocalamus longispathus* (Bu)
*Gigantochloa macrostachya* (Bu)
*G. levis* (Ph)
**Cordage**
*Bambusa vulgaris* (Ph)
*B. atra* (Ind)
*Dendrocalamus strictus* (Bu)
*D. merrillianus* (Ph)
*Dinochloa scandens* (Ind)
*Pseudostachyum polymorphum* (Bu)
**Inner layer of culm sheath as cheroot wrapper**
*Dendrocalamus hamiltonii* (Bu)
**Plaited shoes**
*Dinochloa compactiflora* (Bu)
**Boat masts**
*Bambusa blumeana* (Ph)
*Dendrocalamus brandisi*
*Gigantochloa levis* (Ph)
**Joints for cooking glutinous rice**
*Cephalostachyum pergracile* (Bu)
*C. burmanicum* (Bu)
**Bridges**
*Bambusa blumeana* (Ph)
*B. vulgaris* (Ph)
*B. arundinacea* (Ph)
**Boat plying rods**
*Bambusa polymorpha* (Ba, Bu, Ind)
*B. glaucescens* (Ind)
*Melocanna baccifera* (Ba, Bu)
**Rickshaw hoods**
*Bambusa vulgaris* (Ba)
**Pea sticks**
*Thamnocalamus spathiflora* (In)
**Barbecue skewers**
*Bambusa blumeana*
**Trellises**
*Bambusa arundinacea* (In)
*B. blumeana* (In)
All large-sized bamboos
**Flues**
*Bambusa blumeana* (Ph)
*B. glaucescens* (Ph)
*Schizostachyum lumampao* (Ph)
**Hats**
*Bambusa blumeana* (Ph)
*B. vulgaris* (Ph)
**Barrels for toy cannons**
*Bambusa blumeana* (Ph)
*Gigantochloa levis* (Ph)
**Sledges (transport)**
*Bambusa blumeana* (Ph)
*Dendrocalamus merrillianus* (Ph)
**Handicrafts**
*Bambusa blumeana* (Ph, Ind)
*B. vulgaris*
*Dendrocalamus asper* (Ind)
*Dinochloa scandens* (Ind)
*Gigantochloa verticillata*
*G. atter*
*G. apus*
*Nastus elegantissimus*
*Schizostachyum lima* (Ph)
*S. brachycladum*
*S. blumei* (Ind)
All bamboos (Th)
**Sprayers**
*Bambusa blumeana* (Ph)
**Polo mallets**
*Bambusa blumeana* (Ph)

*(continued)*

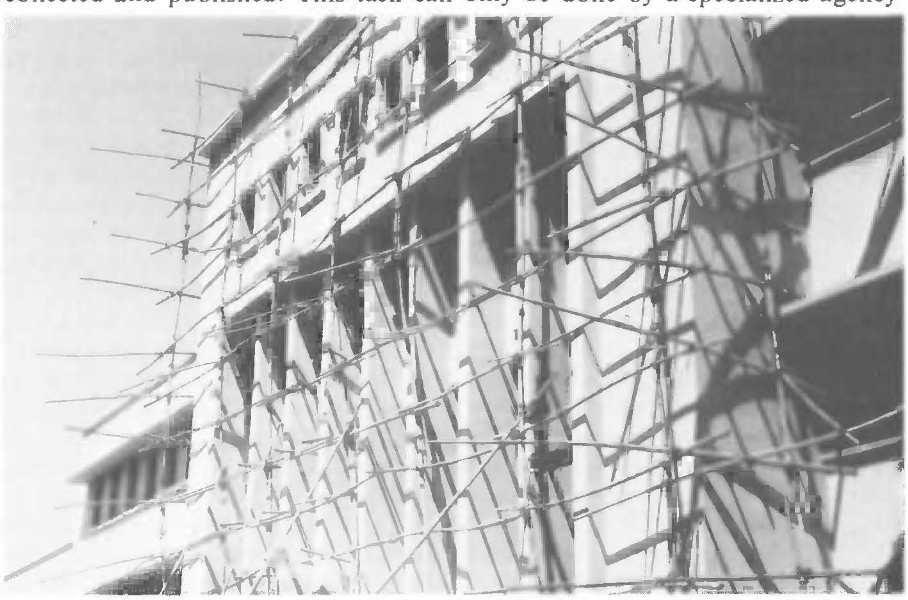
*(Table 1 concluded)*

**Umbrella handles**
*Melocanna baccifera* (Ba, Bu)
*Oxytenanthera stocksii* (Ind)
*Teinostachyum griffithii* (Ba, Bu)
*Thyrsostachys siamensis* (Bu)
**Shuttles**
*Bambusa blumeana* (Ph)
**Piculan**
*Bambusa glaucescens* (Ind)
**Tobacco drying**
*Dinochloa scandens* (Ind)
*Nastus elegantissimus* (Ind)
*Phyllostachys edulis* (Jap)
**Eyeliner**
*Dinochloa scandens*(Ind)
**Jaundice treatment**
*Bambusa vulgaris* (Ind)
**Ladders**
*Bambusa arundinacea* (Ind)
*Dendrocalamus strictus* (Ind)
**Afforestation of riverbanks and soil conservation areas; shelter belts; windbreaks**
All bamboos

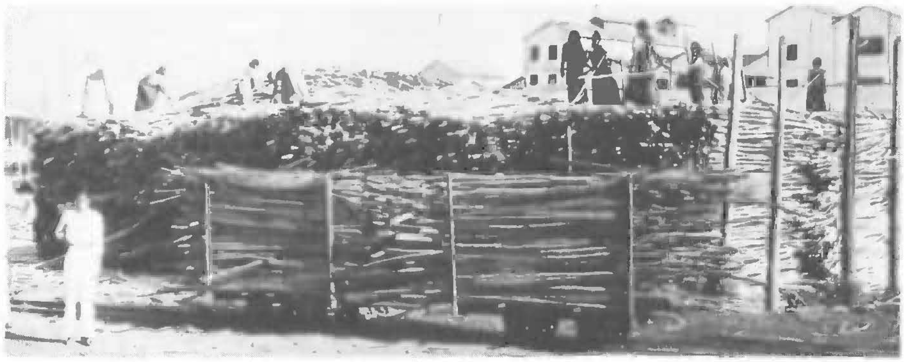
## Research: Past, Present, and Future

There is great scope for research on bamboos in all the countries of the region. During the Eighth World Forestry Congress (held in Jakarta), the question of how to coordinate research on bamboo was discussed. Today, meaningful coordination of research activities on bamboos in the region and exchange of information among researchers are still needed.

In the past, research in India concentrated on *Dendrocalamus strictus*, and not much was done on other species. The same was the case in Burma. Bamboo research had not received the necessary importance in any other countries except Japan and perhaps China. In fact, it has gained importance only during the last 5–6 years. Now research is in progress on methods of seed storage, identification of bamboos by the characters of the culm sheaths on the new shoots and rhizomes. India had a symposium on bamboos in 1963 and another in 1980 in South India, and there is extensive literature available, although it needs to be collected and published. This task can only be done by a specialized agency



*Bamboo scaffolding in India.*



*Bamboo for paper in India.*

financed by an international body because it means extensive travel all over the countries and collection of information.

India now plans to establish three major centres of research and development of bamboos. The station in the North will oversee study of *Dendrocalamus strictus* and *Bambusa arundinacea*. The station in the East will take care of *Melocanna baccifera*, and the station in the South will take care of *Bambusa arundinacea, Dendrocalamus strictus*, and *Ochlandra* species. Imaginative research involving distant crosses like the bamboo–sugarcane cross, attempted decades ago at Coimbatore, is being considered. If this endeavour were successful in selection of quick-growing bamboo varieties, bamboo farming could be taken up on a large scale.

In a recent Southern Forest Research Worker's Conference held at Dharwar, India, during March 1980, the need for research centres on bamboos in each state was stressed. The lines of research suggested were

- Raising bamboo orchards as germ-plasm banks;
- Breeding better varieties;
- Propagating bamboos with tissue culture;
- Undertaking trials on fertilization and irrigation;
- Stepping up propaganda encouraging bamboo cultivation;
- Investigating effective measures for storage and distribution of seeds;
- Initiating experiments on natural regeneration;
- Experimenting with bamboo shoot farms; and
- Researching preservative treatments of bamboos and their use in rural housing.

These suggestions apply to many other countries of the region as well. In view of the large number of species of bamboos in the tropics, intensive research is needed on the ecologic and phenologic aspects of the bamboos.

Experiments on vegetative propagation techniques are in progress at the Forest Research Institute, Chittagong, Bangladesh; if easy methods of vegetative propagation could be devised, the bamboo industry could be revolutionized. Bangladesh has raised a large bamboo orchard of several species near Dacca as a source for germ plasm, and other useful work is being carried out at the Forest Research Institute in Chittagong.

In the Forest Research Institute, College, Laguna, Philippines, considerable work is in progress. One of the important experiments is creating deformity in bamboos for their use in housing. Bamboos (*Bambusa vulgaris*) have been made to grow into square, rectangular, and triangular shapes for low-cost housing, handicrafts, decorative items, and cottages. The project is financed by UNDP (United Nations Development Programme). These artificially shaped bamboos are expected to be stronger than the round bamboo.

Japan has successfully grown artificially shaped bamboos. Production is simple, like moulding hollow blocks, but needs practice. A wooden frame (mould) is made in the desired shape, and it is installed on the young bamboo shoot. After about 6 months the frame (mould) is removed from the bamboo, which has taken on the desired shape. The culm is cut when it matures. The wooden frame can be used again. In Japan and Taiwan if ornamental bamboo culms are needed, a mixture of sulfuric, nitric, and hydrochloric acids with water and clay is prepared and painted over the green culm with a brush; this process produces ornamental patches on the culm. Other ongoing research on bamboo in the Philippines deals with anatomy, preservation, and harvesting methods.

As a complement to identification of species of bamboos based on the culm sheath and its characteristics, experiments should be initiated to find out whether the internodal length and diameter of the culm at a particular internode — for example, the third from the base — are constant for the species. Such a characteristic would form a useful rule of thumb for identification.

In view of the acute demand for bamboos, the possibility of harvesting bamboos annually has to be investigated and in fact is being looked into by the University of Agricultural Sciences, Dharwar, India.

Research on the single-stemmed and nonclump-forming species suited as windbreaks has to be initiated in the different countries. Also research on seasoning and treatment of bamboos with easily procurable and cheap methods needs to be initiated in all countries so that bamboo, a cheap material for construction, can replace timber.

Research on induced flowering and on the methods of establishing bamboo plantations, their management techniques, economic evaluation, and chemical treatment is needed.

Research of interest is being carried out in the herbarium attached to the Royal Forest Department and in the Kanchanaburi Research Centre in Thailand. The Royal Forest Department of Thailand has established five regional research centres on bamboo in the different climatic zones of the country, but the research programs are faced with a shortage of funds. Thailand is centrally situated among the countries of the Asia-Pacific Region from Pakistan to Indonesia, and the Kanchanaburi Research Centre should be converted into an international research centre on bamboos. Regional research centres should be established in the other countries of the region. Financial support should come from international organizations, participating countries, and banking institutions.

## What Is to Be Done?

For bamboo to play a greater role in the development of the region, I feel that specific action other than initiation of research is warranted. For example, an aggressive social forestry practice is needed in countries like India where the dry zone is vast with few or no forests of economic value. Bamboo is one of the species for social forestry; it also can be extensively used in urban areas in parks for ornamental purposes, landslide areas, and along drainage channels.

In areas where shifting cultivation and soil erosion are problems (India, Bangladesh, Thailand) or where soil stabilization is of immediate necessity (Bangladesh), bamboo belts should be grown along contours, other crops being grown in the space between the belts. Bangladesh has an agreement with the

Swedish International Development Authority to raise about 32 000 hectares of forest plantations in this region; bamboo should be one of the species raised.

In Indonesia there is considerable scope for raising bamboos under various social forestry practices; financial support could be provided through forest cooperatives and also through Perum Perutani (forest corporation). The Perum Perutani and the reforestation wing of the Forestry Department should be able to tackle large-scale planting of bamboo to restock cleared areas. Bamboos can be grown alone or mixed with other species like tea and *Albizzia falcatoria*. In Thailand, also, there is great scope for bamboo propagation, especially *Dendrocalamus asper* and *Bambusa blumeana*, the latter being already grown as windbreaks around farms.

A field where there is great scope to increase the potentialities of bamboo is the underplanting of teak plantations after the first or second thinnings. Teak and bamboo form a natural mixture, the bamboo acting as an understory. This practice should be possible in India, Bangladesh, Burma, Thailand, and Indonesia.

A survey of bamboo wealth is urgently needed in all the countries of the Asia-Pacific Region. Forest departments throughout the region have so far relegated bamboo to a secondary position to teak, softwoods, and industrial woods. Bamboos, which are essential to the economy, should be given equal status with the best of timbers.

In the context of the economy in India, bamboo should be one of the species to be given priority in afforestation plans now being drawn up.

The possibilities of establishing bamboo shoot farms in different countries should be explored.

In almost all states in India and in Indonesia, forest corporations have been established to grow fast-growing and other timber species. These corporations should take up large-scale and intensive production of bamboo, adopting techniques suitable to the locale in either pure or mixed stands. In India, Bangladesh, Burma, Indonesia, and Thailand, bamboos are being cleared for afforestation with teak and other woods. Wherever forests with bamboo are taken up for clear-felling, some natural bamboo clumps should be retained.

Bamboos in government forests should not be given free to anyone except in emergencies, such as for rehabilitation of fire or flood victims. All bamboos in areas other than private lands should be extracted by a government agency, i.e., the department of forests or forest corporations, and sold to the public or industry. Additional staff should be employed for this task. Clump-forming bamboos should be worked on a "culm-selection" basis in a felling cycle of, say 2–4 years, and clumps should not be clear-felled. The working of the clumps should be on a thinning cycle.

Gregarious flowering is a rare phenomenon. In countries where bamboos have not seeded or where seed is scanty, bamboo seeds from other countries should be obtained, and large nurseries should be raised.

In view of the excellent scope that bamboos offer for many articles, artisan training centres should be established in each country where there are large varieties of bamboos. Training expertise could be obtained from Japan, China, and other countries. This would increase employment and would even earn foreign exchange.

Participants of workshops such as this one should take note of the vital role played by bamboos in the rural and urban life of the people of the different countries of the Asia-Pacific Region, recognize bamboos on an equal footing with other timber species, implement projects to develop this natural asset, and initiate more experiments in various aspects of bamboo development. It may not be out of place here to suggest that an international study team connected with bamboo be constituted with necessary funding to undertake the preparation of a document of all aspects of bamboos occurring in countries other than those of the Asia-Pacific Region like tropical Africa, South America, and other like countries to make the story complete. It would also be worthwhile to establish a high-level monitoring team to visit at frequent intervals the different countries, review the research on bamboo, and report to the International Union of Forestry Research Organizations for purposes of coordination.

# Bamboo Taxonomy in the Indo-Malesian Region

Soejatmi Dransfield[1]

Present knowledge of bamboo taxonomy in the Indo-Malesian region (Indian subcontinent, Sri Lanka, Bangladesh, Burma, Indochina, and Malesia) is discussed. Twenty genera are recognized and each of them is given a short diagnostic field character. A checklist of species of some genera is also given but is only preliminary.

Bamboos have a tree-like habit yet are members of the grass family, the Gramineae. They have sometimes been treated as a different family from the Gramineae; however most agrostologists agree to keep them in Gramineae, in the subfamily Bambusoideae. All members of the bamboos possess similar anatomical features in the leaf blades, that is fusoid cells and arm cells, that separate the bamboos from the grasses. Some herbaceous genera in the Gramineae have anatomical features as well as some other characters in common with the bamboos. These genera are included in the same subfamily and are considered as a primitive group in the subfamily.

Bamboos can be characterized as having woody, usually hollow, culms, a complex rhizome system, petiolate leaf blades, branches at the culm nodes, and a prominent sheathing organ. Some bamboo species are believed to produce flowers once, after 20–30 years, and then die. Some other species produce flowers the whole year round and do not die after flowering. The basic unit of the reproductive phase, the spikelet or the pseudospikelet, has one to several flowers or florets. In general, the bamboo floret has three lodicules, six stamens, and an ovary with three stigmas. Many parts of bamboo plants, such as culm sheaths, internodes, and also inflorescences are often covered by light-brown to dark-brown, or black stiff, irritant hairs.

Bamboos occur mostly in natural vegetation of tropical, subtropical, and temperate regions and are found in great abundance in tropical Asia. There are about 750 species in about 45 genera. Many of them are indigenous to the monsoon areas of tropical Asia and have a limited distribution. Many of them are found only in cultivation. The distribution of bamboos has been greatly modified by human intervention (166).

As a rule classification of flowering plants, including bamboos, is based mainly on the structure of the flower. Previously, botanists (Ruprecht, Munro) named bamboo plants from flowering specimens, but because bamboos often flower infrequently, naming them in this way is of little use to field-workers acquainted with the living plants. Recently, botanists (Kurz, Holttum, McClure) have suggested and used almost all parts of bamboo plants in naming, classifying, and recognizing bamboo species.

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[1]Dransfield is working independently on the taxonomy of bamboos.

This paper presents the state of knowledge of bamboo taxonomy in the Indo-Malesian region, covering India, Sri Lanka, Bangladesh, Burma, Indochina, and Malesia (Malaysia, Philippines, Indonesia, and Papua New Guinea).

## History of Bamboo Taxonomy

The first bamboo genus, *Bambusa*, was published and described by Schreber in 1789. It was based on one species, *B. arundinacea*, a thorny bamboo from India. Since then, many genera and species have been described and published.

The first comprehensive work on bamboo taxonomy is that of Ruprecht (345). This work is based mainly on herbarium specimens and on previous literature. Ruprecht apparently recognized 67 species of nine genera. His work was followed by more extensive work by Colonel Munro (260). The work includes bamboo species of the world and is also based on the herbarium and literature. Munro recognized about 170 species of 21 genera and divided the genera into three divisions. The first one consisted of the genera that possess three stamens and three stigmas in the flowers and culms without thorns, for example *Arundinaria*. The second group included the so-called true bamboos, *Bambusa, Gigantochloa*, etc. The third group consisted of genera that are characterized by the peculiar structure of the fruit, a thick pericarp enclosing the seed or embryo. Of 21 genera, about 14 occur in tropical Asia, comprising about 120 species. Munro's system of classification has now been adopted as the basis of bamboo classification, such as by Bentham (43) and E.G. Camus (63), with some modification.

After Munro's work, many bamboo articles have been concerned with local floras. In 1876, Kurz, who spent time in the botanic gardens in Bogor (Indonesia), and then in Calcutta (India), and studied bamboos as living plants, published a valuable account on the use of bamboos and the bamboo species occurring in Asia (209). Kurz was the first botanist who studied the bamboos as living specimens and introduced the importance of the vegetative characters, such as culm sheaths, in recognizing bamboo species. He, however, did not propose any formal classification of bamboos.

In 1896, Gamble, who was once a forest botanist in India, produced a monograph of the *Bambusae of British India*, which includes the Indian subcontinent, Burma, and Malaya (104). Gamble traveled much in India and recognized the importance of vegetative characters in identifying bamboo species. His system of classification was adopted from Bentham's system. Gamble's work remains as a fundamental work for Indian bamboos. He recognized about 15 genera.

Blanco (48) published and described many plant species from the Philippines, including bamboos, without collecting the plants. His descriptions are very short and brief; many local names are cited. All bamboos were described under the name *Bambusa*. Later, Merrill (253) interpreted and published Blanco's species of *Bambusa*; they belong to other genera, such as *Gigantochloa, Schizostachyum, Dendrocalamus*, or *Dinochloa*. Gamble (105) described many species of bamboos sent by Merrill, but because Gamble was familiar only with the Indian bamboos, some of his interpretations were wrong. Since then, there has been no taxonomic work on the bamboos of the Philippines, which I believe is rich in native bamboo species. Many of Merrill's names and Gamble's names of bamboo species are still being used. In my opinion, they should be revised.

The account of bamboos in Java was made by Backer (25), and many of Rumphius' names (344) were cited as synonyms.

The bamboos from Indochina can be found in the works of E.G. Camus and A. Camus (63, 64).

Holttum, who was the director of the botanic gardens in Singapore, published his excellent account on bamboos of the Malay Peninsula in 1958 (166). His work is now basic to the region and its adjacent countries, such as Indonesia. Some years earlier he published a suggested new classification of bamboos differing from that of Munro and that of Gamble (adopted from Bentham). His classification is based mainly on the structure of the ovary. Holttum's classification was supported by Grosser and Liese (112) working on wood anatomy of the Asiatic bamboos. However, they did not propose any formal classification.

It seems that by employing different structures, for example fruit structure of Munro's and ovary structure of Holttum's, one can arrive at different conclusions.

Although McClure (244, 246) did not propose any new formal bamboo classification, his suggestions on using all parts of vegetative characters and of flower structure have been accepted both for identifying bamboo species and in classifying the bamboos. Unfortunately until now a formal classification on bamboos based on several characters has not been published.

## Bamboo Genera in the Indo-Malesian Region

The 20 genera recognized in this paper are adopted from various authors; they are Gamble (104, India, Sri Lanka, and Burma; 105, Philippines), Merrill (253), Backer (25, Java), Holttum (166, Malay Peninsula; 165, New Guinea), Lin (221, Thailand), and McClure (244, 246).

I have included a short description of each genus based either on other authors' descriptions or on my personal field observations and study of the herbarium specimens.

It is already known that in bamboos there are two types of root system (244): pachymorph and leptomorph. Nearly all native bamboos in the Indo-Malesian Region have pachymorph rhizome. There are also principally two types of spikelets in bamboos: the ordinary, typical grass spikelet and the so-called pseudospikelet. The former consists of glumes (two or more), one or more florets, each with a lemma, a palea, stamens, an ovary, and lodicules (if present). The spikelets are usually borne in a panicle or in raceme. The latter was introduced by McClure (247) to separate it from the true spikelet because it consists of a true spikelet, one or more lateral branch buds below the true spikelet, and a prophyll at the base. The pseudospikelets are borne in lateral branches or in a special flowering branch of up to 3 m long. The true spikelet is found in five genera occurring in the Indo-Malesian Region, *Arundinaria, Racemobambos, Nastus, Yushania, Thamnocalamus*, and the pseudospikelet is found in the other 15 genera.

I have arranged the genera on the basis of the two types of spikelet together with their natural relationships; for example the genera that are related to each other are put one after another. A checklist of species of each genus (except *Arundinaria* and *Dinochloa*) is also given under the genus concerned. The number of species in each genus is preliminary, because it is expected that there are still many undescribed bamboo species in places like Burma, Indochina, Palawan, Luzon, Mindanao, Borneo, Sumatra, Sulawesi, the Moluccas, etc.

***Arundinaria* Michaux**

*Arundinaria* is a bamboo genus of temperate countries in Asia (Japan, China, Korea, the Himalayas, the northern part of Indochina) and Madagascar. The genus was described in 1803 by Michaux. Since then, the number of species has increased enormously. There are about 480 published names, but many of them have now been put into other genera, for example *Yushania, Thamnocalamus, Sasa, Indocalamus*, etc. Many *Arundinaria* species were introduced to Europe, North America, and in the mountains of the tropics.

***Yushania* Keng**

*Yushania* is a small genus found in Taiwan and in Luzon (Philippines). The genus was described based on *Arundinaria niitakayamensis* from Taiwan, which differs from the typical *Arundinaria* species in having two stigmas in its flower. *Y. niitakayamensis* is also found in Luzon. This genus is very little known, even though botanists have recognized it as a distinct genus from *Arundinaria.* More intensive investigation of this genus is needed. There is a possibility that some species of other genera related to *Arundinaria*, such as *Racemobambos*, belong to *Yushania.*

***Racemobambos* Holttum**

The genus *Racemobambos* is confined to Malesia, especially Malaya, North Borneo, Ceram, and New Guinea and its surrounding islands, and is found only in montane forest. There are about 10 species in the genus, and each species has a limited distribution. The use of this bamboo is not known. The species of *Racemobambos* are scrambling or scandent bamboos. In the field they can be recognized by their thin-walled culms and the many branches in each culm node. The spikelet has three glumes and more than one floret. The species are *R. ceramica* Ceram (Indonesia); *R. congesta* New Guinea; *R. gibbsiae* Mt. Kinabalu, Borneo (Malaysia); *R. glabra* Sarawak, Sabah (Malaysia); *R. hirsuta* Mt. Kinabalu (Malaysia), not certain; *R. hirta* New Guinea; *R. multiramosa* New Guinea; *R. raynalii* New Guinea; *R. rigidifolia* Sabah (Malaysia), not certain; *R. schultzei* New Guinea; *R. setifera* Malay Peninsula; and *R. tesselata* Mt. Kinabalu (Malaysia), not certain.

***Nastus* Nees**

The genus *Nastus* is found mainly in the southern hemisphere from Madagascar to Solomon Islands. In Malesia, there are about 11 species, each of them having a very limited distribution and being found only in the montane vegetation.

The vegetative parts resemble those of *Racemobambos*, so it is rather difficult to separate them without flowers. *Nastus* has one floret with several glumes in the spikelet. The only species found in Java, *N. elegantissimus*, is found in a small area in West Java. It is used for poles for the drying of tobacco leaves by local people. The species are *N. elatus* New Guinea; *N. elegantissimus* Java; *N. holttumianus* New Guinea; *N. hooglandii* New Guinea; *N. longispicula* New Guinea; *N. obtusus* New Guinea; *N. productus* New Guinea, Solomon Islands; *N. reholttumianus* Flores (Lesser Sunda Islands); *N. rudimentifer* New Guinea; *N. schlechteri* New Guinea; and *N. schmudtzii* Flores (Lesser Sunda Islands).

***Thamnocalamus* Munro**

*Thamnocalamus* is a genus of temperate climates in Asia. Two species are found in the Himalayas. *T. spathiflorus* was introduced to Europe as an ornamental plant. The species of this genus were included in the genus *Arundinaria*. The genus differs from *Arundinaria* in having many branches of the same level and size in each node. The species are *T. aristatus* Himalaya; and *T. spathiflorus* Himalaya.

***Bambusa* Schreb.**

With the exception of *B. vulgaris*, *Bambusa* was confined to Asia until McClure (246) transferred the genus *Guadua* of tropical America to *Bambusa*. There are about 30 species of *Bambusa* in tropical Asia. Many of them are among the most useful plants. The species are diverse vegetatively and in flowering behaviour, but they share a similar structure in having a many-flowered spikelet. It seems that there are two groups of species of *Bambusa* in Asia. The first group includes species that have long internodes and a thin-walled culm and are found usually in the mountains. They flower all the time, and they do not die after flowering. The second group consists of species that have shorter internodes and a thick-walled culm. They grow usually in the lowlands and flower infrequently. Holttum (166) suggested that the first group probably belong to another genus, but they are still retained in the genus *Bambusa*. Further investigation is required.

Two species, *B. arundinacea* and *B. blumeana*, produce excellent pulp for paper making. The species of *Bambusa* are used for building materials, only when there are no other bamboos, such as *Dendrocalamus* or *Gigantochloa*, available.

The species of *Bambusa* can usually be recognized in the field from the culm sheaths; diagnostic characters are the presence of auricles, erect blades, and dark-brown hairs on the sheath. Certain species can be recognized easily, for example by their thorny lower branches, as in *B. arundinacea* and *B. blumeana*, other species by the alternate arrangement of lateral branches along the culm, as in *B. vulgaris*. The species are *B. amahussana* Moluccas; *B. arundinacea (B. bambos)* planted or wild in Asia; *B. atra* Moluccas, New Guinea; *B. balcoa* Bangladesh, India, Burma; *B. binghamii* Burma; *B. blumeana (B. spinosa)* planted and wild in tropical Asia; *B. brevicephala* New Guinea; *B. brassii* New Guinea; *B. burmanica* Burma, Thailand, Malay Peninsula; *B. cornuta* Luzon, not certain; *B. forbesii* New Guinea; *B. fruticosa* New Guinea; *B. glaucescens (B. nana, B. multiplex)* ornamental or hedge plant in the tropics; *B. heterostachya* Malay Peninsula; *B. hirsuta* New Guinea; *B. horsfieldii* Java, not certain; *B. klossii* Malay Peninsula; *B. magica* Malay Peninsula; *B. microcephala* New Guinea; *B. montana* Malay Peninsula; *B. pallida* Burma, Thailand; *B. pauciflora* Malay Peninsula; *B. pierreana* Indochina; *B. polymorpha* Burma, India, Bangladesh, Thailand; *B. ridleyi* Malay Peninsula; *B. riparia* New Guinea; *B. solomonensis* Solomon Islands; *B. tulda* India, Bangladesh, Burma; *B. ventricosa* China, introduced in Southeast Asia as an ornamental plant; *B. vulgaris* planted in the tropics; and *B. wrayi* Malay Peninsula, Sabah; etc.

***Gigantochloa* Kurz**

Most species of *Gigantochloa* are useful for local people and are planted for everyday use in villages. The genus is confined to the area from Burma, Indochina to Malay Peninsula and the Philippines. None of the species in Java are native; they are believed to have been introduced from the Asian mainland during the migration of people from the North. Two Javanese species, *G. atter* and *G. verticillata*, are planted widely in Java and have no relatives in the Asian mainland. It seems there has been selection by humans long ago. The species are usually found in the lowlands. *Gigantochloa* species have culms with relatively thick walls. The culms are usually very durable as compared with those of *Bambusa*. The size of the culm varies from species to species. They can be as large as 20 cm in diameter and as tall as 30 m as in *G. levis* in Sabah. The species with large culms are often confused with another genus, *Dendrocalamus*, whose culms are very often 20 cm in diameter (*D. asper* and *D. giganteus*).

In the field *Gigantochloa* can be recognized by the straight culms, the absence of prominent auricles on the culm sheaths, the long blade of the culm sheath, and the node, which is not swollen. The culms usually have short branches at the node.

There are about nine species altogether in *Gigantochloa*, but the genus needs to be revised. The species of *Gigantochloa* have never been recorded to flower gregariously as in the case of *Bambusa* spp. and *Dendrocalamus* spp., but sometimes all the culms of one or more clumps produce flowers. It is not known whether the plant (or the clump) dies after flowering or only the culms that produce flowers. The species are *G. apus* Java, planted; *G. hasskarliana* Malay Peninsula, Java, planted; *G. latifolia* Malay Peninsula, probably in South Thailand too; *G. levis* Malay Peninsula, Philippines (Luzon), Sabah; *G. ligulata* Malay Peninsula, Thailand; *G. ridleyi* Malay Peninsula; *G. scortechenii* Malay Peninsula; *G. wrayi* Malay Peninsula; and *G. verticillata* Java, planted (including *G. maxima* and *G. robusta*); etc.

### *Dendrocalamus* Nees

There are about 10 species in *Dendrocalamus*, and they are mainly found wild in the lowlands from India to Indochina and the Malay Peninsula. One of them, *D. asper*, is planted everywhere in the archipelago, from the lowlands to about 1000 m in altitude (Toraja, Sulawesi). Its culms are highly prized as building material. It has a thick wall, a diameter up to 20 cm. The shoot of this species is considered one of the best for food.

In the field, the genus can be recognized by its thick-walled culms, swollen nodes, and aerial roots at the lower nodes. The species usually have white or light-brown hairs on the culm sheaths.

One species of the genus, *D. strictus*, is well-known in producing flowers gregariously. The culm is also the source of pulp for paper making. The species are *D. asper* planted everywhere in Southeast Asia; *D. brandisi* India, Thailand, Burma; *D. dumosus* Malay Peninsula; *D. elegans* Malay Peninsula; *D. giganteus* native in Burma, introduced elsewhere in Southeast Asia; *D. hirtellus* Malay Peninsula; *D. membranaceus* India, Thailand, Burma; *D. pendulus* Malay Peninsula; *D. sinuatus* Malay Peninsula; and *D. strictus* India, Burma, Thailand.

### *Thyrsostachys* Gamble

*Thyrsostachys* is native in Thailand and Burma and consists of about two species. One species, *T. siamensis*, has been introduced to other countries and is now established as an ornamental plant in Malaysia and Indonesia. It has slender, erect culms that have branches only in the upper nodes. In the field it can be recognized by its compact clump with erect, slender culms and its narrow leaf blades. In its native country it is used for basket making, fences, etc.; it is also used as raw material for paper making. The species are *T. oliveri* Burma, Thailand; and *T. siamensis* Burma, Thailand.

***Oxytenanthera* Munro**

*Oxytenanthera* is an African genus, *O. abyssinica* being widespread in Africa. Eight species in the genus were described from Asia, but the position of these species in the genus is doubtful as discussed by Holttum (166). He suggested that the Asiatic species of *Oxytenanthera* belong to either *Dendrocalamus* or *Gigantochloa*. An intensive investigation of the genus is required. Most of the Asiatic species are found in the mainland.

***Phyllostachys* Sieb. et Zucc.**

*Phyllostachys* is a genus of subtropic and temperate regions of Asia, extending to Himalaya, with its centre of distribution in China. Many of the species were introduced to Europe, North America, and the mountains in the tropics such as in Java. Species of this genus are useful bamboos in their native countries, such as in China and in Japan. In the tropics, for example in Java, they are used as an ornamental and hedge plant, and the culms are used for local industry in items for which the strong culms are needed, such as in umbrella handles.

The genus is easily recognized by a combination of various vegetative characters, including straight culms with swollen nodes; furrowed internodes along its entire length, especially above the node bearing a fully developed branch complement; branches typically two in each node; leaf blades with tessellate venation; and culm sheath glabrous, narrowed toward the top. The shape of the internode is so characteristic for the genus that it enables one to recognize the genus from only a piece of dried culm. However, the species are difficult to differentiate. There are about 30 species in the genus; three species were introduced to Java, only one species, *P. aurea*, has established itself in limited areas in Central Java.

***Schizostachyum* Nees**

In the field, *Schizostachyum* is easily recognized by its thin-walled culms (except *S. caudatum* from Sumatra, which has almost solid culms). Almost all species of *Schizostachyum* produce flowers the whole year round. The spikelets are slender, 1–3 cm long. The diameter of the culm varies from species to species; for example *S. brachycladum* has culms with a diameter of about 7 cm, whereas *S. longispiculatum* has culms with a diameter up to 1 cm. The culms are light, yet durable, and easily split. There are about 22 species in the genus, and they are found from Thailand throughout Malesia. Many species are confined to very small areas. Most of the species are found growing wild or spontaneously along roadsides, near villages, or in the forest. This is probably the reason that most *Schizostachyum* species are widely used by local people. The culms are used for making rafts, flooring, roofing, baskets, handicrafts, etc.

Not all species are useful. *S. grande*, found only in the Malay Peninsula, became a smothering weed in the hill dipterocarp forest after the area was logged. The culms are about 6 cm in diameter, have a very thin wall, and are useless.

Some species in the Philippines described under *Schizostachyum* may belong to a different genus. In this listing, they are not included. An investigation of the genus is much needed. Species are *S. aciculare* Malay Peninsula; *S. alopecurus* New Guinea; *S. biflorum* Java; *S. blumei* Sumatra, Java, Borneo, probably Sulawesi; *S. brachycladum* planted or wild in Southeast Asia; *S. brachythyrsus* New Guinea; *S. caudatum* Sumatra; *S. gracile* Malay Peninsula; *S. grande* Malay Peninsula; *S. insulare* Malay Peninsula; *S. iraten* Java, not certain; *S. jaculans* Malay Peninsula, probably Borneo; *S. lima* Philippines, Sulawesi, Moluccas, New Guinea, probably Borneo; *S. longispiculatum* Malay Peninsula, Borneo; *S. lumampao* Luzon; *S. serpentinum* Java, not certain; *S. terminale* Malay Peninsula; *S. whitei* New Guinea; and *S. zollingeri* Malay Peninsula, Java, Sumatra, Sulawesi, and probably Borneo; etc.

***Cephalostachyum* Munro**

*Cephalostachyum* is a genus of about seven species occurring in the areas between northeast Himalaya, Assam, and Burma to Thailand. They are usually shrubby or arborescent bamboos, with thin-walled culms. One species, *C. pergracile*, has been introduced and planted in the botanic gardens in Singapore and in Bogor (Indonesia).

Holttum (166) suggested that *Cephalostachyum* species should be included in the genus *Schizostachyum* on the basis of the structure of the spikelet. I think it is reasonable to treat *Cephalostachyum* as distinct from *Schizostachyum* until monographic work of each genus is done.

In their native countries *Cephalostachyum* species are useful for basket making. The species are (104) *C. capittatum* Bangladesh, Burma; *C. fuchsianum* Bangladesh, Burma; *C. flavescence* Burma; *C. latifolium* Bangladesh, Burma; *C. pallidum* Bangladesh, Burma; *C. pergracile* Bangladesh, India, Thailand; and *C. virgatum* Burma.

***Teinostachyum* Munro**

*Teinostachyum* is a small genus of three species occurring in Sri Lanka, India (Assam), Burma, and probably in Indochina. Each of the species has a very limited distribution. As in the case of *Cephalostachyum*, Holttum (166) also suggested that *Teinostachyum* should be included in the genus *Schizostachyum*. In my opinion *Teinostachyum* should be kept separate from *Schizostachyum* until monographic work is done. The species are *T. attenuatum* Sri Lanka; *T. griffithii* Bangladesh, Burma; and *T. wightii* India.

***Neohouzeoua* A. Camus**

*Neohouzeoua* is also a small genus of about four species occurring in the areas between Assam and the northern part of Indochina. Two of the species were transferred from the genus *Teinostachyum*. *Neohouzeoua* is related to *Schizostachyum* in having thin-walled culms. Little is known about its natural history or its uses. The species are *N. dulloa* Burma, Indochina; *N. helferi* Burma; *N. mekongensis* Indochina; and *N. stricta* Burma.

***Pseudostachyum* Munro**

*Pseudostachyum* is a monotypic genus found in east Himalaya, Assam, and Upper Burma. *P. polymorphus* is a large shrub and easily recognized by its thin-walled culms and its commonly diseased inflorescences full of galls. Local people use this bamboo for making baskets.

***Melocanna* Trin.**

*Melocanna* has apparently one species only, *M. baccifera*, which is found in Bangladesh, Assam, and Burma. It has been introduced elsewhere in the tropics. *M. baccifera* is a very interesting bamboo from many points of view. In the areas where it grows, this species is a very useful plant for all purposes, such as building material, basketry, etc. This bamboo produces flowers gregariously and then dies. The fruit is large, sometimes as large as a pear. It has a thick pericarp, no endosperm, and an embryo with a large scutellum. It germinates when it is still on the parent plant (i.e., it is viviparous).

In the field, this species can be recognized by its open clump and erect culms with intact culm sheaths that have long narrow blades.

***Ochlandra* Thwaites**

*Ochlandra* is found in Sri Lanka and in southern India. There are about six species in the genus. *Ochlandra* is also an interesting bamboo genus, because all species have relatively large fruits with thick pericarp, such as those of *Melocanna* but smaller, and also a large number of floral parts, especially the stamens (as many as 120 in one floret). Little is known about the natural history of the genus, and more intensive investigation is required. The culms of *O. travancorica*, which is found abundantly in South India, produce good quality fibre for paper and rayon. The species are *O. brandisii* India; *O. rheedii* India; *O. setigera* India; *O. stridula* Sri Lanka; *O. travancorica* India; and *O. wightii* India.

***Dinochloa* Büse**

*Dinochloa* species are climbing bamboos. There are about 20 species in the genus, found growing in the forests of Thailand and throughout Malesia. Each species has a limited distribution except for *D. scandens*, which is widespread in the western part of Malesia. In the field, the genus is easily recognized by its climbing habit with zigzag culms. Mature culms are strong and are usually used by local people as material for making rough baskets to carry stones. Other uses are not known. In cleared or logged forests, such as in Sabah, *Dinochloa* species can become a very serious weed problem, preventing regeneration of commercial timber.

From a taxonomic point of view, *Dinochloa* is a very interesting genus. The inflorescence is huge, up to 3 m long, leafless, bearing a large number of very small spikelets, and producing a large number of fruits. The fruit has also a thick pericarp, no endosperm, and an embryo with large scutellum. Because *Dinochloa* species are useless economically, little is known of their natural history. At the moment, I am conducting a taxonomic study, and, thus, this listing of species is not complete, including only *D. aguilari* Luzon; *D. mcclelandii* India, Burma, Thailand; *D. luconiae* Luzon; *D. pubiramea* Philippines; and *D. scandens* western part of Malesia.

***Melocalamus* Bentham**

*Melocalamus* is monotypic with its species *M. compactiflorus*. It is found growing wild in the mountains from eastern Bangladesh to northwest Thailand. This species is also very interesting. It is related to *Dinochloa*. It has a large fruit with a thick pericarp, no endosperm, and an embryo with large scutellum. It was recorded that the fruits germinate while they are still on the parent plant. Little is known about its natural history.

In the area where this species grows, local people use it for making baskets.

## Conclusions and Suggestions

It is already widely understood that researchers working on a particular aspect (anatomy, cytology, cytogenetics, etc.) of a certain plant need the correct botanic name as a point of reference. Local names have to be avoided, for they often cause much confusion; for example, local names often apply to more than one plant, and they differ from place to place. Botanic or scientific names have precise meaning. An example in bamboos: *Dendrocalamus asper* (synonyms: *Bambusa aspera, Dendrocalamus flagellifer*) belongs to the genus *Dendrocalamus*, which has a thick-walled culm of a good quality. This species is found planted throughout Indonesia and is supposed to be native to Burma. It is called *betung* or *petung* in Java and *bambu Jawa* in North Sulawesi because it is believed to come from Java. *D. asper* produces the best-quality bamboo shoots. *Poring* is a local name of a common bamboo in Sabah. It has culms of variable size, 10–20 cm in diameter and up to 30 m tall. It was identified as *D. asper* because of its size. However, anyone wishing to invest in this bamboo as a source of good bamboo shoots for export would be disappointed. Careful study of its morphology showed *poring* to be a species of *Gigantochloa, G. levis,* which has culms with thinner walls and poorer shoots than those of *D. asper*. Another example: "Malaysian bamboo" is used as a name for a bamboo species introduced into Africa as a tool for harvesting the fruit of oil-palm plantations. Actually there are more than a dozen bamboos native to Malaysia, so no one knows which species the "Malaysian bamboo" is. For this reason cooperation between taxonomists and others is required.

An inventory of bamboo species should be carried out in each country in Southeast Asia. For this purpose herbarium collections of bamboos are needed. If there is no botanist in a particular area, then the material should be sent to an institution where a bamboo taxonomist works or where a good collection of bamboos with correct botanic names is available for identification (Appendix).

The inventory can be extended to a systematic study (including revision) on a particular group of bamboos. As with many flowering plants, bamboo must be studied in the field so that it can be studied as a living material. This work or study can be done intensively by local botanists who have plenty of opportunities to see bamboos in the field. However, international cooperation should be regarded as a part of this study. In any systematic or taxonomic study, type specimens of the plants and early literature should be consulted. Many earlier botanists specializing in Indo-Malesian bamboos worked at the Royal Botanic Gardens, Kew (U.K.), so that most of the type specimens are deposited there. Furthermore, earlier foresters in the east sent bamboo material to Kew either to be named or to expand the general collection. It is suggested that any botanist who wishes to work on the systematics of Asiatic bamboos, especially from India, consult the Kew collections.

From the taxonomic point of view, bamboos present many interesting problems. At present, I am working on the delimitation of each Indo-Malesian genus, but such work depends very much on field observations that cannot be done at Kew. In some cases, however, a good collection of bamboo plants with complete field notes and a photograph of the plant (Appendix) can be very helpful in this work. Again international cooperation is needed.

In the modern concept of plant taxonomy (78), all aspects of investigation are employed in plant classification, including anatomy, cytology, phytochemistry, physiology, embryology, and ecology. Classification of grasses (excluding bamboos) is a good example of this modern concept and should be extended to bamboos. Wood anatomy, leaf anatomy, and embryo of many bamboos have already been investigated. Any information on all these aspects would be welcome and would be very useful for future bamboo classification.

Inventory work can be carried out in conjunction with ethnobotanic work; the result could be practical, local guides to bamboo identification and uses.

# Lessons from Past Studies on the Propagation of Bamboos

S. M. Hasan[1]

A number of papers on flowering habit, seeding cycle, propagation by seed, and vegetative methods of bamboos have been studied, and it has been found that a lot of information is available in bits and pieces. To date, no serious attempt has been made to analyze this information; this paper attempts such an analysis, concluding that various physiologic, genetic, and ecologic factors have made the study of seeding behaviour of bamboos very complex. It is suggested that a new area for research on this subject should be based on the use of seeds. Regional cooperation for the exchange of seeds and information will be necessary if such a program is to be comprehensive and successful. Seed-production areas need to be established from all natural and induced out-of-phase seedings and, where necessary, multiplied vegetatively. Such measures are likely to make seed available in bulk and more frequently.

In the field of vegetative propagation, well-differentiated tissues have been used almost exclusively in experiments — a fact that is probably responsible for the high degree of failures. Undifferentiated cells that are found in preexisting primordial structures in culm buds may be a useful material for future studies, which should employ the media and methods being applied in tissue-culture techniques.

The economic, ecologic, and silvicultural importance of bamboos in South and Southeast Asia is phenomenal. In this region, bamboos are widely distributed in forest areas and also cultivated in village groves. In many countries bamboo has become an integral part of the village economy and is extensively used for cheap housing and items for domestic and agricultural uses, including food and feed. Lately it is being extensively used for industrial purposes such as the manufacture of paper, rayon, cellophane, etc.

Concern about bamboo areas in the forest has arisen from the fact that in some countries they are being overexploited. The result has been what is regarded as the first stages in the annihilation of this important group of forest products. In the village groves mainly thick-walled bamboos, with limited local utility, are cultivated. These, however, would be highly useful for the pulp industry if the villagers were willing to feed such mills. Unfortunately, this is not always the case. The thin-walled species, which are more suitable for construction of cheap houses, are relatively difficult to propagate and are seldom cultivated; they abound in the inaccessible areas of forests and are the main raw material for the pulp mills. These facts have created a wide imbalance between production and utilization.

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The abundance of bamboo in South and Southeast Asia is probably responsible for the apathy toward its development. Concern usually comes only when a resource is completely lacking or is scarce. Some countries of this region have begun to feel the pinch of depleting stocks, whereas others are apathetic, and still others are engaged in wanton destruction of the resource because they are not aware of its utility and importance. The first step toward correcting the imbalance between production and utilization of bamboos is creating an awareness of the depleted stocks. Persons who have studied the economics of bamboos are convinced that the main impediment in the maximum utilization of this renewable resource is its propagation.

In the past, all studies on bamboos were made in natural stands, as it was thought that the world stocks of bamboos are sufficient to last perpetually. However, McClure (248) and I (137) have studied forests adjacent to human habitations and those exploited for industrial purposes and have found that the assumption of everlasting stocks of natural bamboos is not correct. Continued excessive cutting results in reduced yield of bamboos and, eventually, their extermination. Bamboo-growing areas have receded, and the process of recession, which probably ends in extermination, demands artificial restocking of the depleted areas.

Studies on the propagation of bamboos started in the last decade of the 19th century. In 1893 the Government of India issued a circular that has been incorporated in forest manuals in Bangladesh and elsewhere (7), setting out requirements for reporting all seedings of bamboos. Pathak (312) made the first attempt to propagate *Dendrocalamus strictus* by cuttings. Since then about 120 papers on flowering behaviour, 150 papers on seeding cycle, and about 40 papers on the results of propagation by seed have been published. Also about 80 papers on vegetative propagation of bamboos have been published. Some of the papers include information of far-reaching consequences, and, when the information from different sources is put together, it leads to some practical conclusions. Such compilations have been made earlier by Janzen (179) for seeding behaviour and McClure (244) for vegetative propagation. However, none of these attempts have resulted in a solution of the problem or in the establishment of a standard technology for raising bamboos artificially. At present, a different approach is being taken; it includes both seeding behaviour and vegetative propagation. A brief summary of the attempts and their analysis should help in the planning of future research programs on the propagation of bamboos.

## Propagation by Seed

Possibilities of raising bamboo plantations from seed are limited because many bamboos produce seeds only two or three times a century. Most attempts in the past have concentrated on determining the seeding cycle. The hope was to be able to forecast seeding. The method was to record the seeding in forests and estimate the seeding cycle from past documents or from accounts by villagers nearby. Although considerable observations on the seeding of different species of bamboos have been made and reported, they have lacked information on the regions where flowering occurred and, thus, have done little to clarify the uncertainty about seeding cycles.

It has been possible, however, to determine the exact seeding cycle of species introduced into regions outside their natural habitat. Dutra (85) reported that *Bambusa arundinacea* was introduced in Brazil probably from an 1804 seeding in Coorg (India) and that it flowered in 1836, 1868, and 1899, giving a seeding cycle of 31–32 years. Clement (72) reported that *Dendrocalamus strictus* was introduced in Cuba probably from a 1912 seeding in Gharwal (India) and that it flowered in 1956 — a seeding cycle of 44 years. Wang and Chen (459) reported that a plantation of *D. strictus* raised in 1922 in Taiwan from seed from Bihar (India) flowered in 1969 — a seeding cycle of 47 years. Bor (53) recorded that *Thyrsostachys oliveri*, planted in 1891 in Dehra Dun from seed from Burma, flowered in 1939 — a seeding cycle of 48 years. These are the only cases for which the exact seeding cycle (from seed to seed) is known. In the case of all other species, the information is rather speculative.

In natural stands, the question of seeding cycle is not as easy as it may appear because of the physiologic, genetic, and ecologic factors involved.

**Out-of-Phase Flowering**

From a study of the published work, it is clear that most bamboo species produce seed once in their lifetime; the event appears to be caused by an internal physiologic calendar that controls the length of the vegetative period. Variations occur, and they seem to be due to environmental factors that cause an accidental breakdown of the physiologic shield. The result is that the plant flowers at a different time from the original plant, but the length of the vegetative period remains unchanged. In 1978, I (142) suggested that in *Melocanna baccifera* there are a normal and a number of out-of-phase flowerings. The normal is gregarious flowering over large areas such as occurred during 1958–61 and has been reported from extensive areas in Assam (278, 279), Bangladesh (139), and Burma. Seeds from a few clumps, however, were collected in Bangladesh in 1974 and 1975, which is in the middle of the normal seeding cycle. In *Bambusa tulda* and *Dendrocalamus longispathus*, gregarious seeding of the nature of *M. baccifera* has not been reported, but sporadic flowering extending over an area of one-fourth to several hectares has been recorded in Bangladesh for a number of years in different regions. Prasad (323) has reported similar seedings in *B. tulda* for a number of years in different regions of Bangladesh and Burma. These variants may be considered varieties, as they behave similarly from generation to generation in respect to flowering. This factor makes a study of seeding habit in natural stands complicated.

**Flowering Habit**

With a few exceptions, grasses are characterized by semelpary; however, all grades of iteropary have been reported in bamboos. For example, Gamble (104) and Rhind (339) recorded *B. lineata* as a regularly flowering species. In 1966, McClure (244) recorded that *B. tuldoides* flowered for more than 42 years before dying in Honduras and that *Arundinaria amabilis* and *Phyllostachys nidularia* flowered gregariously for more than 10 years before dying and gradually recovering from rhizomes. Bean (42) recorded the flowering of a few clumps of *A. simonii* for 14 years, the clumps dying every year but recovering from rhizomes. At the Forest Research Institute, Chittagong, partial flowering of some clumps for a few years and complete flowering of other clumps in 1 year before dying has been recorded for *B. glaucescens* and *D. longispathus*. The same phenomenon was reported by Mathauda (241) in the case of *D. strictus* from India. In *B. glaucescens, D. longispathus,* and *D. strictus* these different forms of flowering habits do exist. It is not clear whether they also occur in other species. Further systematic research on the subject is necessary. The causes of such variations have not been investigated but are probably inherent characteristics of the species.

## Genetic Mutation

Long vegetative periods before flowering are not peculiar to bamboos, being rather a general dendroid character. All trees have a longer or shorter vegetative period before they begin to flower. Larsen (212) found that the age at which trees first flower is under genetic control. He observed that, in teak, flowering normally starts at age 8–10 years with considerable individual variation. Trees have been observed to flower at age 3 months, but a few used in genetic selection have not flowered by age 27 years. The variable length of the vegetative period prior to flowering is also common to bamboos, which are arborescent grasses. Changes in the length of the vegetative period and, hence, different seeding cycles, are probably due to genetic mutation.

From seeds of *Bambusa tulda* sown at the Forest Research Institute, Chittagong, a few 2–3-year-old seedlings flowered and produced seeds. Of 39 clumps raised from the seeds of these seedlings, 16 have behaved similarly to the mother plant, and the others have not yet flowered. It is too early to make any comments other than that the two groups are genetically different. From India, similarly, seeds were produced by 2–3-year-old seedlings of *Dendrocalamus strictus* (6, 47), but a follow up with the progeny has not been attempted. In *D. strictus*, three; in *B. arundinacea*, two; and in *Oxytenanthera abyssinica*, three seeding cycles appear to exist. For *D. strictus*, Kadambi (182) suggested a seeding cycle of 25 years in Mysore State (south India); Gupta (129) suggested a seeding cycle of 40 years from north India; and Mathauda (241), 65 years also in north India. Similarly for *B. arundinacea*, Nicholson (281) suggested a seeding cycle of 32 years in Orissa, and Blatter (51) suggested a seeding cycle of 45 years from Bombay State (south India). From East Africa, Fanshaw (97) suggested a seeding cycle of 7 and 21 years for *Oxytenanthera abyssinica* in Kenya and Adlard (3), 15 years in Malawi. Clumps raised in Brazil from seeds taken from Coorg gave a seeding cycle of 31–32 years for *B. arundinacea* (85). This cycle is the same as that suggested by Nicholson (281) for the clumps in Coorg. The actual seeding cycle for *D. strictus* obtained in Cuba (72) is very near that suggested by Gupta (129). The seed imported in Cuba was reported to be taken from Gharwal, and Gupta's suggestion is from seeding in Bihar. Thus, the bamboos in different regions appear genetically different. The genetic diversities occur in far-flung regions and can be taken as provenance. The variations are probably caused by genetic mutations due to geographic factors.

## Natural Hybrids

Free hybridization between species produces forms of diverse nature. In my studies, I (135) found that seeds collected from natural stands of *D. longispathus* produced clumps that show variation in morphologic characters such as the culm sheaths, culm buds, branching habit of culm buds, presence or absence of supranodal ridge, and the time that leaves or branches regularly fall. I (136) also reported the occurrence of variation in clump forms and order of breaking of culm buds in different clumps in *B. polymorpha* raised from offsets and collected from different localities. In *B. arundinacea*, Bahadur et al. (26) found that seedlings showed right-handed and left-handed folding of the first leaf and that the left-handed ones grew faster. Kondas et al. (204) identified four different types of seedlings in *B. arundinacea*, which they called grassy, grassy erect, erect, and very erect. The erect and the very erect types were more vigorous and were faster-growing. The authors suggested that the shoot thickness and internode length could be used for selection purposes. The erect types accumulated dry matter more quickly than did the spreading types. Natural crosses between species only occur when the flowering time of different species is the same — a rare occasion. Within a species, this is common. Variations that appear to be controlled genetically can be seen even while the clumps are growing; variations in seeding behaviour can only be seen when the clumps flower. When a species flowers, the variation in the nature of flowering and seeding cycle, etc., inherent in the clump, is expressed, and the individuals in a population behave differently depending on their distribution in the area. It is necessary to study and analyze the causes of variation in the progeny raised from seed.

### Mixed Natural Stands

All natural stands are a mixture of species not only of diverse morphologic characters but also of different forms with different seeding behaviour. From the literature, it appears that sporadic flowering has been interpreted as a precursor to gregarious flowering. The ecologic distribution of individuals is responsible for sporadic and gregarious flowering. Often large areas in natural stands have been seeded simultaneously and thus flower gregariously. Stands can be created artificially that will flower gregariously or sporadically.

In the past, all studies on seeding behaviour have been carried out in natural stands, which comprise genetically variable clumps and clumps from out-of-phase flowering with different seeding times. To get a correct picture, one must limit the variables, and at present, this means studying individual clumps and not the population. It is increasingly important to study the behaviour of progeny of seeds. Therefore, it is necessary to raise arboreta, gene banks, and seed stands. Gene banks should include not only morphologic variables but also variables with regard to seeding behaviour. Also, special seed-production areas consisting of varieties flowering at different times are needed so that seed may be made available more often and may be used for the raising of plantations at will. For this purpose regional cooperation for the exchange of seeds and other planting materials is necessary. In cases where the number of clumps is few and the quantity of seed produced is likely to be small, the progeny may be multiplied by vegetative propagation.

## Vegetative Propagation

The most important limiting factor in the cultivation of bamboos is the difficulty of obtaining regeneration artificially. At present, some propagation is carried out by vegetative methods. In species with leptomorph rhizomes, which are found in temperate regions only, Oh and Aoh (290) found that planting rhizome cuttings, 40–50 cm long, 10 cm deep gave good results. This method has become the normal practice in Korea where 1000 rhizome cuttings are planted per hectare. In species with pachymorph rhizomes, which are commonly found in tropical and subtropical regions, offsets are used but are bulky, heavy, and difficult to handle and transport. Also, only a limited supply of the planting material needed for offsets is available per clump; therefore, this method is impractical for use in large plantation programs. In 1977, I (141) found that using branch cuttings instead of offsets overcame the difficulty of scarcity, bulk, and weight of planting material but that success in propagation was very limited. Early researchers, like Pathak (312), Lin (223), and Chinte (70), failed to draw a distinction between dicots and monocots, and they tried to use culm segments in somewhat the same way as these are used in sugarcane. Their observations were limited to a short period. When they observed the development of sprouts from the nodes, they all hastened to publish the results, classifying bamboos as easy to propagate by culm segments. Similarly, Cabanday (61) tried ground- and air-layering of culms and culm buds and also reported good percentages of success in a few species. These studies have one major flaw in common: the researchers did not wait to see how the propagules fared after being planted in the field. If they had, they would have found that the propagules soon die. Clones do not become fieldworthy unless rhizomes have been formed and new shoots start emerging. Abeels (2), who tried branch cutting, came to the conclusion that as long as the swollen basal portion of the branch was present, the planting medium did not matter. McClure and Durand (249) pointed out that, in the matter of striking roots, the basal buds are slow to sprout and during this time the planted materials often die, with the result that the percentage of success is low. My studies (141) have shown that branch cuttings take 6–30 months to develop into good planting material. Roots may develop in 6–12 months, but the development of rhizome takes 12–36 months, and the planted material that fails to develop rhizome ultimately dies. In fact, the planting material continues to die until the rhizome develops. I also found that the use of humidity tents and sealed tins prolongs the life of the cuttings but does not improve the rooting. White (462) and Delgado (79) pointed out that root-promoting substances, at the normal concentrations, have no effect. Because of the difficulty of obtaining satisfactory results with or without root-promoting substances and because of the long period of waiting (30–36 months), none of the current vegetative methods can be said to be easy or economic.

An examination of the structure of the material used for experimentation indicates the reasons for the low percentage of success. My studies (141) have led me to conclude that the branches are miniature culms. The basal portion of both is swollen. In the case of culm the swelling is known as rhizome and in the case of branches it has been termed rhizomatous swelling of branch bases. The swollen bases of the branches are morphologically and, under certain conditions, physiologically similar to the rhizome, and they can be made to function like it as well. Both consist of well-differentiated tissues. There is no meristematic tissue except that in the buds. Porterfield (320) studied the morphology of growth in bamboos and concluded that the sheath primordia are the first appendages to emerge behind the apex of the growing point. Next to emerge are the primordia of the buds subtended by each sheath. The axis of the bamboo plant elongates principally during the "grand period of growth." The elongation is effected by means of intercalary growth. The apex of the growing point is protected by many layers of overlapping sheaths. Recently, I (140) found that bamboo buds consist of primordial structures that are rhizome-like and have partly preformed sheaths attached to a meristematic band. This meristematic tissue represents the nodes and internodes of the branches only; the root primordia are borne outside. From any textbook of botany it can be learned that the process of differentiation of tissue and enlargement of cells consists of the formation of a vacuole; as the cell enlarges and the protoplasm spreads along the cell wall, the vacuole degenerates and the cell wall starts thickening. The cells, therefore, lose all potential to divide and only act as strengthening, conducting, or storage tissue. In most monocots, the meristematic activity is limited to set structures — mainly the bud. It does not spring up anywhere on the body of the plant. Once a tissue has been differentiated, it does not have tissue-adding properties, and, therefore, no new primordia for root and rhizome development are formed. The textbooks also indicate that the protoplasm is the active substance that, under the influence of environmental factors, produces biologically active chemicals responsible for initiating differentiation. Due to the absence of protoplasm in well-differentiated tissue, no such activity takes place. The development of rhizome is dependent on the biologic condition of the buds on the rhizomatous swelling. These buds, being the softest part on bamboo culms, are easily attacked by insects and other organisms. All such buds are normally dead and do not develop.

It is clear that, for all practical purposes, different forms of the same material, that is, well-differentiated tissue, have been used, in trials to date, and for this reason the use of different media seems to have produced no effect on rooting. It is now time that the planting material be changed to undifferentiated cells. It is only the preexisting primordia or the primordial structures in the bud that are physiologically active and that can produce branches or other plant parts. The easy rooting of sugarcane is probably due to the presence of undifferentiated cells in the nodes even after the growth of the culms is complete. The media and the methods to be adopted should be similar to those used in tissue culture.

According to the findings of Porterfield (320), Tomar (421), McClure (244), and many other workers, it is clear that the shoot growth in grasses and particularly in bamboos, instead of being terminal, is intercalary. Venkatraman (456) published photographs that clearly show the elongation of internodes to be at the base. Except for the terminal bud of the rhizome and the rhizomatous swelling, there is no terminal bud and the growth in length is caused by elongation of the internodes. The growth of individual primordial structures starts from the centre of the cone-like structure and proceeds outward so that the smallest preformed sheath in the centre comes out first and becomes the topmost node and the largest outermost preformed sheath becomes the lowest node above the rhizomatous swelling of the branch. At first the meristematic activity is spread over the entire node; however, as the elongation of the cells goes on to form the internodes, the nodes are separated and the meristematic activity shrinks, ultimately being confined to the bud. No other part of the fully grown branch has this property. Cobin (1947) noted that some plants of *B. textilis* had an abundance of roots on the bases of the branches, a circumstance that he attributed to the poorly drained condition of the soil. In 1977, I (141) noted such rooting on some branches of other species that were growing in well-drained soils. Probably the rooting preceded the completed differentiation of the cells or resulted from some cells that remained undifferentiated. The sparse development of roots from the nodes of bamboos, under normal conditions, indicates that the number of undifferentiated cells is very low and, therefore, the striking of roots, even under favourable conditions such as those during experiments, is low. Probably the experimental material to be used in the future should be undifferentiated tissue or the primordial structures in the bud.

## Concluding Remarks

In the past, all studies on seeding behaviour of bamboos have been made in natural stands, and, hence, even after 100 years of study, regeneration in bamboos is not clearly understood. In natural forests, a number of factors militate against controlled studies, including out-of-phase flowering; species with various grades of iteropary and others with semelpary; genetic mutations in respect of length of vegetative period prior to flowering; natural hybrids; and the ecologic distribution of diverse forms in the same area resulting in mixed stands. It is necessary to change the strategy of research. The seed must be used as a tool of research, and all seedings must be optimally utilized. The length of the vegetative period has clearly emerged in bamboos raised as exotics from seeds. It is, therefore, necessary to establish research areas where all the species of economic importance can be planted from all the seedings that come to light. Meticulous records of the behaviour of individual clumps and their progenitors must be kept, and it is likely that regional cooperation for exchange of seeds and information is necessary for a successful program.

The seeding behaviour of bamboos indicates that it is possible to induce out-of-phase flowering. Research on this subject should produce new out-of-phase flowering strains that are at present nonexistent in nature. In the meantime, seed-production areas can be created with all natural out-of-phase seedings, and induced flowerings can make seed available every year.

This is a long, drawn-out process and, till such time as the fruits of the attempts are available, other methods will have to be used, including propagation with materials other than seeds. It is clear, from a brief review, that all known methods, except for tissue culture, have been tried without much success. My studies of culm buds (140) have shown that primordial structures in culm buds can be used in tissue-culture trials and need to be taken up at an early date.

# Propagation of Bamboos by Clonal Methods and by Seed

Ratan Lal Banik[1]

Bamboo can be propagated vegetatively and by seeds. Rural people generally cultivate this plant by offsets and rhizomes. For large-scale plantations these methods are not economic due to scarcity of planting materials and transport costs, which are high because of the bulkiness of the materials. In the past, people tried other vegetative methods, such as culm segments, branch cuttings, ground — and air — layering, etc. But in all cases, the success was poor. Failure might have been due to inadequate knowledge of the propagating materials. In this paper some aspects of biology of bamboo propagation are discussed. It is pointed out that the age, nature, and the location of propagating material should be considered for better success. Development of roots and rhizome in propagating materials probably ensures success in bamboo plantation. This condition might be achieved by manipulation of the internal physiologic and external ecologic condition of the planting material. Propagation by seed is hindered because it is unavailable for long intervals.

Besides normal flowering, bamboo sometimes may undergo out-of-phase flowering. Out-of-phase flowering is identifiable, as it only occurs in small areas or in a few clumps. It is important because it makes seed available between the normal seeding cycle. Plants originating from out-of-phase seed may be termed varieties. These varieties are expected to maintain the same length of seeding cycle as the species but to flower at different times. This hypothesis can be confirmed at the next flowering of such varieties. The varieties could be physiologically or genetically evolved. If all the out-of-phase varieties were collected and planted in one place, seed could be available every year or after short intervals, at least, for a few bamboo species. International and zonal cooperation in creating seed-producing centres is needed; and this could be achieved through international "varietal" seed exchange and regular scientific communications. Early flowering of seedlings may provide material for hybridization with species of normal-flowering patterns.

Seed germination and the period of viability in a few bamboo species of Bangladesh are reported. Seedling care and selection for plantation programs are also discussed.

Bamboos are very unevenly distributed in the tropics, subtropics, and mild temperate regions of the world, from sea level to the snow line. By far the greatest number of species is found in the Indo-Malesian region, extending through China to Korea and Japan. To the people of these countries, the manifold rural

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uses and some industrial uses of bamboo are well-known. As a result, bamboo afforestation programs are gaining priority.

So far, about 33 species of bamboo have been found in Bangladesh. Nearly eight are found in the forest areas. The forest species are generally thin-walled, usually grow in pure stands, but sometimes in mixtures of two or more species, associated with trees. The most important species is *Melocanna baccifera* (Roxb.) Kurz; other species like *Bambusa tulda* Roxb., *Dendrocalamus longispathus* Kurz, *Neohouzeoua dulloa* A. Camus, *Melocalamus compactiflorus* (Kurz) Bentham, *Dendrocalamus hamiltonii* Munro, *Oxytenanthera nigrociliata* Munro, and *Oxytenanthera albociliata* Munro, grow sporadically. The thick-walled species are cultivated in the villages. Among them, *Bambusa vulgaris* Schrad, *Bambusa nutans* Wallich ex Munro, *Bambusa balcoa* Roxb., *B. burmanica* Gamble, *B. arundinacea* Retz., and *Dendrocalamus calostachyus* Kurz, are the most common.

The greatest impediment in the maximum utilization of this renewable resource is the difficulty in large-scale production. The use of seeds is restricted because bamboo generally only flowers after long intervals. Large-scale bamboo plantations require sufficient stocks of planting material that is economic to produce and convenient to transport. For a long time people of bamboo-growing areas have been practicing different vegetative methods for propagating this plant. Offset planting and use of rhizome cuttings are the most popular in villages and the countryside. Nearly a century ago, Peal (315) showed that propagation of bamboos by offset planting was common in the villages of Assam and Bengal.

For small-scale village groves, offset planting is generally favoured. Though *Melocanna baccifera* is one of the major bamboo crops of the forest areas of Bangladesh, only a few clumps of this species can be seen in the village groves. Practical experience has shown that planting of partial clumps of this species gives better results than offset planting. The plant has a pachymorph rhizome system with strongly elongated neck (up to 1.0–1.5 metres long) in a mature clump. A mature clump of this species needs more space than other village-grove bamboo species and generally cannot withstand heavy human and animal traffic, which compacts the soil and makes it difficult for the emerging culm to penetrate through the soil. Because of its familiarity, offset planting is more common than partial-clump planting. Offsets and rhizomes are used, although they are bulky, heavy (4–30 kg), and difficult to handle and transport. Moreover, a clump can supply these materials in only limited amounts, certainly not enough for large-scale plantations.

Research at the Forest Research Institute, Chittagong, and in some other countries has moved toward the use of branch cuttings as propagating material; however, success with this material has been limited so far. Abeels (2) found that the planting medium such as nursery beds, stagnant water, and sandy beds of streams did not affect the success rate if the branch cuttings included the basal swellings, but Abeels' overall success was only with a few species of bamboos. McClure and Durand (249) pointed out that branch cuttings are slow to form roots and most of them die during the process. Hasan (141) has shown that branch cuttings develop into good planting materials in 6–30 months, depending on the biologic condition of the cutting and the period of the year when the cuttings are taken. Roots may develop in 6–12 months, but the development of rhizome takes 12–36 months; planted material that fails to develop rhizome ultimately dies. The planting material will not survive till both the root and rhizome are developed. White (462) and Delgado (79) have observed that there was no significant effect of normal concentration of hormone on the rooting of branch cuttings. Thus far, in no case has success with branch cuttings been satisfactory.

Pathak (312), Dabral (76), Lin (222, 223), and Chinte (70) have tried using culm sections of bamboo in somewhat the same way as those of sugarcane are used. From very limited observations they concluded that bamboo is easily propagated by culm segments; focusing only on rooting, they did not even mention the development of the rhizome. Troup (424) used culm segments of some bamboo species for propagation, but he opined that sprouting of stem cuttings without rhizomes was very uncertain. Similarly, Cabanday (61) tried ground — and air — layering of culms and culm buds and reported a good percentage of success. But such propagules die soon after being planted in the field; so, in practice, the percentage of success has remained low or very poor.

## Biology of Clonal Propagation

Generally, in higher plants, new cells are chiefly formed by specialized tissues and are localized in certain, more-or-less-organized regions known as meristem. Secondary growth is typically lacking throughout monocotyledons, but anomalous secondary growth is present in some monocots by primary thickening meristem (96). Generally, new growth in monocotyledons is due to primary meristem, although primary meristem may occur in mature tissue. In dicotyledons, the initial growth is due to primary meristem located at the shoot and root apex; secondary growth takes place by lateral meristem (cambium). But in bamboo and other monocots, the meristematic zone is located only in some isolated regions. These are mainly the tip of every growing axis, the zone of intercalary growth just above each node of all actively elongating segmented axes, and dormant but viable bud and root primordia. The meristem of intercalary zones of actively growing segmented axes (rhizomes, culms, or branches) may give rise to root primordia or functional roots in addition to buds (rudimentary leafy axes) (244).

A developing culm possesses all three meristematic zones. But soon after it attains its maximum height and diameter (within 2–3 months of emergence), its meristematic zones become restricted to the buds and root primordia. With a few exceptions, every node of every segmented axis of a bamboo plant bears a bud or a branch, and a branch, in turn, has a bud at every node. As the buds are the only meristematic parts of the culm body, studies in vegetative propagation should involve methods in transforming as many as possible of these innumerable buds into the planting materials.

Recently, a study (140) of the inner structure has shown that rhizome and culm buds are partly differentiated and large enough to be seen without or with slight magnification. Rhizome buds differ from culm buds in being monoprimordial in nature. These buds only give rise to a new culm from the rhizome. The root primordia are borne outside the rhizome buds. The culm buds are generally multiprimordial in nature and consist of rhizome-like structures with shoot, root and, rhizome primordia. The shoot primordia first become active by developing branches on the culm node. The other primordial structures (roots and rhizomes) of culm buds may remain dormant or active depending on, most probably, internal physiologic and environmental conditions. Regularly debudding the rhizome and severing the newly emerged culm from the clump of *B. nutans, B. arundinacea, B. vulgaris, B. polymorpha,* and *B. burmanica* at the bamboo arboretum of the Forest Research Institute, Chittagong, showed the

*Branch bases with developed rhizomes and aerial roots of Bambusa burmanica.*

development of aerial roots and rhizomes at some branch bases of a few clumps of *B. polymorpha, B. vulgaris,* and *B. burmanica* after 2–3 years. Aerial roots generally are observed in warm humid periods of the year (June–August). Removing the emerging culms and the rhizome buds limits the mother rhizome's ability to utilize the carbohydrate reserve to support the newly emerged culms and hence the level of the reserve increases. Probably the increased carbohydrate reserve influences the activation of root and rhizome primordia in the culm bud. Observations indicate that all the primordial structures (especially root and rhizome) of culm buds could be activated by the manipulation of the internal physiologic and climatic conditions depending on the species. It seems that a


*Branch bases with developed rhizomes and aerial roots for Bambusa polymorpha.*

clump treated in this manner may yield many prerooted and prerhizomed branch cuttings that could be used as successful propagules. To facilitate vegetative propagation in bamboos, McClure (244) has stressed the importance of the presence of complete and rooted branches or branch complement. Cobin (1947) reported the successful use of branch cuttings to propagate *Sinocalamus oldhamii, Bambusa vulgaris* var. *vittata,* and *Gigantochloa verticillata.* In all these species, root primordia appear spontaneously in abundance on the swollen part of the principal branch base. Hasan (140) has also studied the arrangement of the primordial structures in the culm bud and found them to have a concentric arrangement. Each structure has two companion structures below it. Such structures up to the third order can normally be seen, and the rest are probably in an invisible stage. This arrangement ensures the continuous growth and augmentation of parts. From the structural arrangement and physiologic potentialities of culm buds, he has concluded that these parts can be used for tissue-culture purposes and that for any tissue-culture trial the entire primordial structures may have to be used as a propagule in contrast to the use of callus tissues in dicots.

Bud dormancy and the breaking of it vary with the nodal position of the bud on the culm, age of culm, and the nature of the species. Takenouchi (414) was the first to call attention to the order of breaking of branch buds on the young culm. In some species the buds open acropetally and in others, basipetally. Observations on this phenomenon have been made for some bamboo species of Bangladesh. In *Neohouzeoua dulloa* and *Melocanna baccifera*, the breaking of bud dormancy on the node of a newly developed culm was found to be in basipetal order, gradually moving toward the base (excepting 2–3 nodes at the culm base) and being completed at age 3–4 years. Although essentially the same pattern was observed in *Bambusa vulgaris*, 5–10 buds around the middle of the culm remained dormant up to 3 years. After that, all opened except those in the 2–3 base nodes. In *Bambusa tulda*, all the buds awakened at nearly the same time with the exception of a few at midculm or slightly below. Most of the remaining buds started opening about age 1–2 years.

Generally, in bamboos, new leaves and branches start developing during mid-March–April from the culm buds and branch buds after each defoliation. The buds are more active in this period than at other times. Thus for good success in a propagation program, buds or branches may be selected just before (January–February) or at the initiation (March–April) of the growth period. White (462) studied the effect of seasonal variations on the rooting of branch cuttings of nine different bamboo species. His results showed that the average rooting percentage was maximum in December (15.8%). Maximum number of species was stimulated during March (six of nine species) and December (five of nine species). The percentage was 10.5 for three species stimulated in June. Poorest success was in September (3.3%), with only two species being stimulated. During the selection of propagating material, the position on the culm, age of material, and period of collection should be considered very carefully.

From the published literature and practical experience, it is evident that there is an optimum age for rooting in each type of propagating material (rhizome, offset, and branch). For example, one rhizome of *Phyllostachys* sp. had not produced any new culm even 7 years after being planted (438). The pachymorph rhizome generally contains 4–6 buds on each side, totaling 8–12 buds. The buds at the basal part of the rhizome become active first and produce culm in the growing season. The other buds remain dormant most of the time. If the emerging culm developed from the basal bud dies or breaks for any reason, the remaining buds become active acropetally for producing new culms. As the rhizome becomes older, the buds also gradually lose their viability and power of activity. Practical experience has shown that rhizomes more than 2 years old generally give poor and unsatisfactory results in propagation.

In culm cuttings, age also plays a vital role in propagating practices. Culm cuttings from *Dendrocalamus strictus* less than 2 years old gave better results for propagation (124) than did older culms.

Similarly, the position of culm buds may have a significant role in propagation. A scientific investigation is necessary to find out the isolated and combined effects of bud position, culm age, and external climatic variations on clonal propagation (layering, cuttings, bud culture, etc.).

A complete bamboo plant consists of three morphologic structures — the aerial part (the culm) and the two underground parts (the rhizome and the root). Success of cuttings of dicots and gymnosperms depends only on the development of leafy axis and roots, but a bamboo propagule must develop all the morphologic structures — the leafy axis, rhizome, and root — for its success. Failure in development of any of these phases leads to complete failure. First of all, a cutting develops leafy axis from the bud(s) of its node(s) within 1–2 weeks of being planted, although this development does not guarantee development of root or rhizome. Striking of roots is slow and delayed (up to 2–4 months). At this stage, all the growth potentials are diverted toward the root primordia to make them active. Cuttings that fail to develop roots die within 2–3 weeks of being planted. Development of a tuft of roots may require more than 6 months. After that, just before the rainy summer, the rhizome primordia become active and may produce culm from the bud in the middle of the growing season (June–September). Appearance of new shoots (culms) on the ground from the rooted materials is the indication of rhizome formation in the cuttings. Time required for rhizome development in branch cuttings may be from 4 to 30 months (141). Cuttings that fail to develop rhizomes may survive up to 4–5 years with the help of roots but without any further shoot growth.

It is clear that bamboo cuttings must develop shoots, roots and rhizomes for success. Hasan (141) tried vegetative propagation through offset and branch cuttings on a few bamboo species of Bangladesh and estimated the percentage of failure in each phase (rooting and rhizome development). When branch cuttings were used, many species showed good rooting response (0.3–100%) but poor rhizome development. Ultimately, in Hasan's study, only very few (0.3–1.1%) of three species producing roots also produced rhizomes. Failure percentage was comparatively less for the offset method, as the planting material already possesses rhizome and root initials.

## Propagation Through Seeds

Bamboo produces seeds after long intervals. Seeding cycles vary from species to species and may be 30–100 years. The exact year or age at which bamboos produce fruit cannot be predicted; therefore, the seeding cycle is normally calculated on the basis of estimation and speculation. However, the exact seeding cycle (from seed to seed) for *B. arundinacea* Retz. has been determined to be 31–32 years in Brazil (85) and 45 years in India (50, 52); the cycle for *D. strictus* Nees was 47 years in Taiwan (54). Therefore, the possibilities of raising bamboo plantations from seeds have been limited, although from a genetic and economic viewpoint, seed is the best method for propagation. Rao (336) in Akola Division and Andiappan and Wilson (9) in Madras State, India, raised successful plantations of *B. burmanica, B. arundinacea,* and *D. strictus* from seed. At present, there is also an active move to raise large-scale bamboo plantations in Madhya Pradesh and other states (363). In Korea, Sa and Joo (346) have raised bamboo plantations by planting mother bamboo rhizomes, stock with rhizomes, and bamboo seedlings. Though they had the same results in all the types of planting stocks, they found the use of bamboo seedlings to be more economic than use of the other two. In recent years, the Forest Research Institute, Chittagong, has started small-scale experimental plantations in

Table 1. Years of seeding in natural forest.

| Species | No. of "varieties" with seeding years | | | | | Total nos. of varieties |
|---|---|---|---|---|---|---|
| | Clonal | 1 | 2 | 3 | 4 | |
| *Melocanna baccifera* | Unknown | 1974 | 1975 | – | – | 3 |
| *Oxytenanthera nigrociliata* | Unknown | 1978 | – | – | – | 2 |
| *Dendrocalamus longispathus* | Unknown | 1974 | 1978 | 1978-79 | 1977–79 | 5 |
| *Bambusa tulda* | Unknown | Seedling flowered at 18 months | 1977 | 1979 | – | 4 |

different parts of the forest area with 1-year-old seedlings of *B. tulda* and *D. longispathus* raised from the seeds of 1977 and 1978.

To overcome the lack of seed, one may collect out-of-phase seed. Studies at the Forest Research Institute, Chittagong, have shown that in *Melocanna baccifera*, there is a normal seeding and a few out-of-phase seedings. The normal seeding is identifiable by its gregarious nature over large areas (139, 278, 279). In 1974 a small area at the foot of Garo Hills (Mymenshing) flowered, and in 1975 a few clumps produced seed in the central districts of Bangladesh (Table 1). The out-of-phase flowering occurs only in small areas or in a few clumps. Out-of-phase flowering is important because it makes seed available in the middle of the normal seeding cycle. Kawamura (194) stressed the importance of distribution of flowering and seeding intensity within a bamboo species — a concept largely ignored by others in their documentation of bamboo flowering and seeding. He and, later on, Numata (285) described the variation in the flowering intensity and seeding cycle of *Phyllostachys henonis* and *P. bambusoides* respectively. From their observations and documentations, Janzen (179) inferred that the variation is due to different clumps (clones within the same species of bamboo) that were slightly out of phase with each other. Unfortunately, no attention was given to within- and between-habitat variation of genetic-versus-phenotypic variation. From the published records of flowering of bamboo species in Bangladesh, Burma, and India during the past 100 years, it appears that most include plants from a number of seed generations. *D. hamiltonii* flowers sporadically almost every year (343) but may also flower gregariously at 30 years' interval (66). *D. strictus* is another of the bamboos whose periodicity is not irrevocably fixed. In fact, it is likely to flower sporadically every year. It has even been recorded that cultivated seedlings have flowered at age 13–14 months (55). These sporadic or out-of-phase flowerings may be considered varieties that make seed available more than once during a seeding cycle. The number of such varieties in species so far collected in the bamboo arboretum of the Forest Research Institute, Chittagong, is given in Table 1; it has been calculated on the basis of clumps of seed and of clonal origin. The seeding of the clumps of clonal origin is not known, and though they have been considered one variety, they may consist of more — a possibility that will be either confirmed or refuted at the next flowering. The varieties appear to result from out-of-phase flowering, probably due to accidental breakdown of the internal calendar of the physiologic shield for flowering (179). They may maintain the same length of cycle as the normal one.

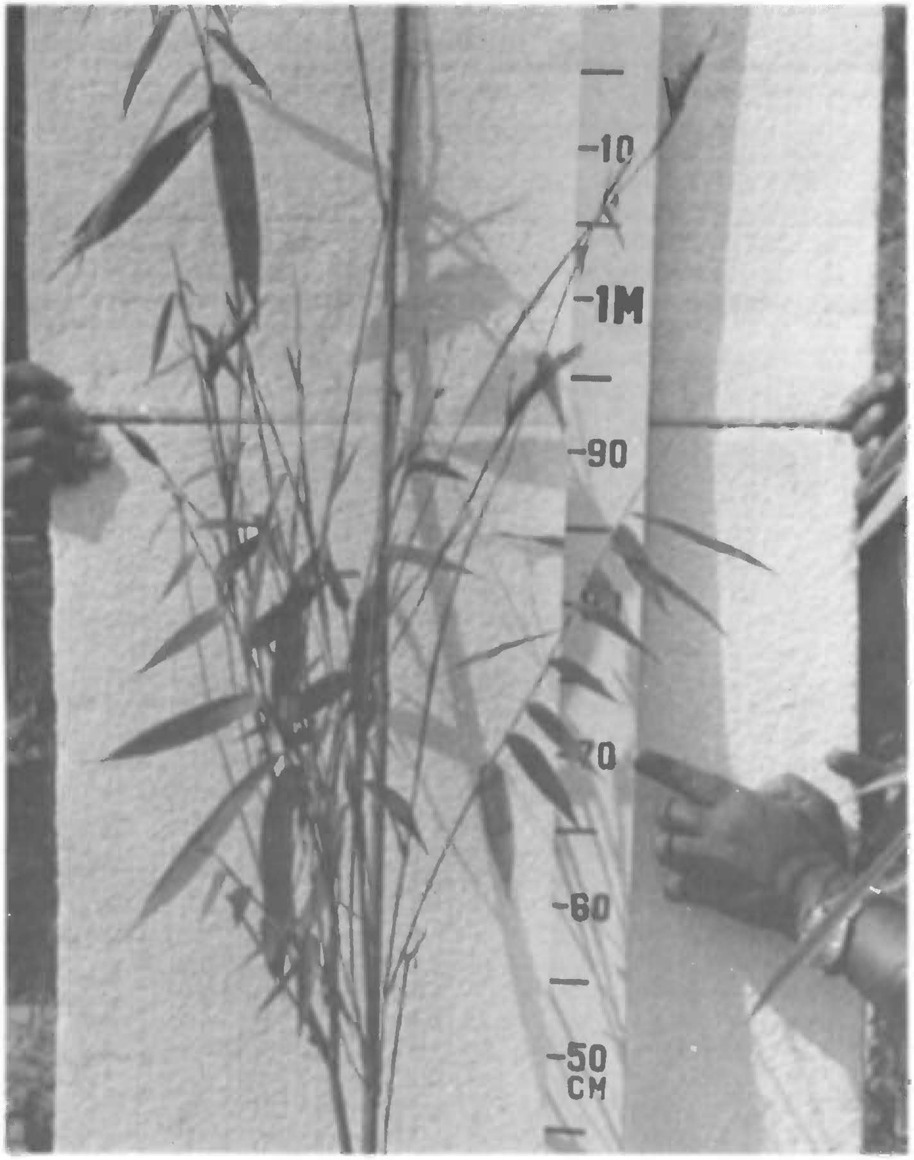
The published records indicate that some varieties transmit their interseeding period to the next generation; such reports justify the designation of varietal evolution due to genetic mutation. *B. arundinacea* planted at Dehra

Dun in northern India had gregarious flowering in 1836, 1881, and 1926, an interseeding period of 45 years (50, 52). This species was also introduced to Brazil and flowered in 1804, 1836, 1868, and 1899, an interseeding period of 31–32 years (85). The seed planted in Brazil was probably a different variety from that planted at Dehra Dun. Blatter (49) reported flowering of *B. arundinacea* on the coast of India in 1804; these plants could have the same parental origin as the plants introduced to Brazil. Three interseeding periods have been reported for *D. strictus*. In Mysore State (south India) the estimated interseeding period is 25 years (182); in Uttar Pradesh (northern India) 40 years (129); and in Hoshiarpur of Punjab (western India) 65 years (241). Observations from different parts of Africa have shown three different interseeding periods — 7, 21 (97), and 15 years (3) — for *Oxytenanthera abyssinica*. In Bangladesh, two seeding cycles have been reported (20 and 30 years)(138) for *B. tulda*. Three such periods 7–10 years (69), 30 years (69, 138), and 45 years (5, 364) were also observed in *Melocanna baccifera* within the area of Bangladesh and the nearby Indian state of Assam. From the present discussion and other reports, it can be concluded that bamboos of this subcontinent generally have a flowering cycle of 20–45 years. A range of 25 to 35 years was regarded by Kurz (209) as the general age at which the common kinds of Malayan and Indian bamboos, belonging to *Bambusa* and *Dendrocalamus*, come into flower. If all the physiologic (?) and genetic mutants of different species in this area were collected and planted in one place, it would be possible within 45–50 years to create seed sources that give seeds every year at least for a few species.

For this purpose every country should have one or more seed-producing centres cooperating internationally through varietal seed exchange and regular scientific communication.

It was recorded in India that cultivated seedlings of *D. strictus* began to flower at 13–14 months (55) and at 2–3 years (6, 8, 128) after being planted. During 1979, of 5000 *B. tulda* seedlings raised in the central nursery of the Forest Research Institute, Chittagong, one flowered at age 18 months. This plant yielded few seeds, but from these seeds 37 seedlings were raised, and of those, 16 flowered at 12 months in February 1980. These 16 produced fertile seeds (90.5%), and 250 seedlings have been raised so far in the second generation. The work will be continued till the achievement of a pure line of generations for this early flowering variety. After that, the early flowering seedling will be crossed with normal flowering *B. tulda* and other *Bambusa* species in hopes that a variety of short interseeding period will be possible.

It has been seen that *B. glaucescens*, *B. arundinacea* var. *spinosa* (?), and *Dendrocalamus longispathus* generally flower from February to June successively in three flushes with two dormant intervals. Seeds from the first two flushes give better germination percentages than do those from the third flush (39). The seeds vary in sizes and shapes. Those for *Bambusa* sp. and *Oxytenanthera* sp. are shaped like wheat, i.e., linear, oblong with either acute or truncated tips and, for *Dendrocalamus* sp., more-or-less ovoid. Sometimes the seeds are bigger and may be shaped like onions (e.g., *Melocanna baccifera*), or they may be spherical (e.g. *Melocalamus compactiflorus*). The number of caryopses (seeds) per kilogram varies from species to species. Nearly 13 900 caryopses of *B. tulda* and 132 000 caryopses of *B. arundinacea* var. *spinosa* (?) constitute 1 kilogram. Seeds are short-lived, losing their viability within 1–2 months. For good germination percentages, it is better to sow freshly collected seeds. I (40) studied the seed germination and viability of five different bamboo species of Bangladesh and obtained the highest germination percentage in *B.*




*Bambusa tulda seedling that flowered at 18 months.*

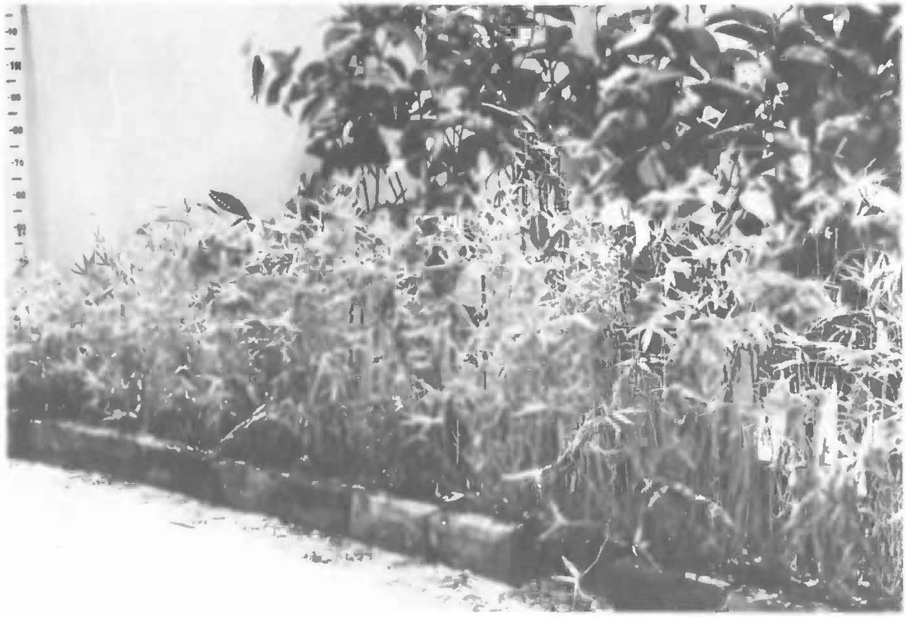
*arundinacea* var. *spinosa* (?) and *D. longispathus* (52.3 and 50.0% respectively). The percentage was 26.4–48.0 in *B. tulda*. I obtained better germination rates from seeds in polythene bags than from those broadcast in nursery beds.

In the nursery, under partial shade, the bamboo seedlings thrived well up to age 5–6 months. Congested seedlings under partial shade at the juvenile stage had more rapid elongation of internode length and photosynthetic surface (leaf) than did those at wider spacings. Also, in the field, closely spaced seedlings would have the advantage of weed suppression.

In nature, many bamboo species after gregarious flowering produce large numbers of seedlings on the forest floor. Of these, many die because of


*Seedlings from Bambusa tulda that had flowered at 18 months flowered at age 12 months.*

suppression and competition by weeds. In forest areas of Sylhet, Bangladesh, it was observed that during 1979 many 1- and 2-year-old seedlings of *B. tulda* were competing with weeds (*Eupatorium odoratum*) for their survival. In the next year many of the regenerating bamboo seedlings were found to be eliminated due to weed competition. So, after each gregarious flowering, foresters of such areas should be careful and alert about the weed problem for the proper regeneration of bamboo. Otherwise, there is every possibility that the areas of natural bamboo forests will decrease after each gregarious flowering. In Burma, Kurz (210) observed similar weed problems for natural regeneration of bamboo seedlings.



*Effects of congestion and shade show in height of 6-month-old seedlings.*

In the nursery of the Forest Research Institute, Bangladesh, three different plant types were identified among the seedlings of *B. glaucescens* during 1978. These were grassy, grassy erect, and erect in nature. The erect type showed faster growth with elongated nodes and wider culm diameters than did the other two types. Kondas et al. (203) observed four different morphologic types — grassy, grassy erect, erect, and very erect — in *B. arundinacea* seedlings at the nursery stage. The erect and very erect types were more vigorous and fast-growing, and, according to them, these types should be selected for plantation due to their growth potential.

It has also been observed that in 1-year-old seedlings of *B. tulda* and *B. glaucescens* culms emerge more or less throughout the year irrespective of seasonal variations. But in the second year there are some months when no culms emerge. This periodicity indicates that rhizome buds in the seedlings remain active throughout the year up to age 1 year and that, if the seedlings were planted within this time, success in field establishment could be much improved.

## Conclusions

A truly successful method for vegetative propagation has not yet been found. Successful propagules must develop roots and rhizomes if they are to survive after being planted. A prerooted and prerhizomed branch cutting may partially fulfill this condition. Therefore, a scientific investigation is needed into the biologic factors responsible for developing roots and rhizomes at the branch base or other propagating materials. Moreover, modern technology like tissue culture should be tried in bamboo investigations.

Collection of out-of-phase seeding varieties is one possible means for overcoming bamboo-seed rarity. Regional cooperation in this regard is essential so that seed-production centres can be built up for bamboo in each country.

# Bamboo Cultivation

Etsuzo Uchimura[1]

Native bamboo species are widely distributed on all the continents except Europe; however, about 80% of the bamboo-growing areas are distributed in South and Southeast Asia. In Japan, the area of useful bamboo forest covers only 0.5% of the total forested area. For this reason, bamboo is generally considered a minor forest product, even though it is a very valuable resource in Japanese daily living. It is used in agricultural and fisheries materials, some instruments, furniture, handicrafts, etc.; therefore continued and increased production of bamboos is required. At present, however, there is too little known about bamboos to guarantee production, and ecologic and physiologic studies are badly needed. Some of the aspects, which are discussed in this paper, include ecological distribution of clump-forming and nonclump-forming types of bamboo; the habits of bamboo genera; the propagation of two types of bamboo through asexual reproduction from rhizome-cuttings (offset planting), culm cuttings, layering, and grafting and through sexual propagation by use of seeds; bamboo cultivation methods as a reflection of meteorologic site, growth of culm and rhizome, stand density, biomass, and fertilizer application; bamboo flowering; and genetics and breeding.

Native bamboos are distributed on all continents except Europe. At present, approximately 50 genera and 700 species of Bambusaceae cover more than 14 million hectares of land, 80% of which is in the South and Southeast Asian tropical regions. Bamboo is important as a resource for food, manufactured goods, etc. It should be considered an important subject for research.

The forest area of Japan covers about 25 million hectares, 67% of the total land area; the useful bamboo forest is only 0.5% of this. Although bamboo is generally considered a minor forest product, it provides important materials for use in house and furniture construction, agricultural or fisheries goods, interior decoration and various handicrafts. In other words, it is indispensable in Japan. Bamboo has also been tried in pulp making but for this purpose requires continuous, large-scale production — a requirement not met in Japan. Recently, studies on the manufacturing process of bamboo charcoal have been taken up in earnest. With all these uses for bamboo, efforts to increase its production both in diameter of individual stalks and in number of shoots have been intensified.

## Distribution of Bamboo Forest and Production of Culms

Bamboo is generally capable of propagating asexually in the form of buds

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growing between rhizomes and culms. The propagation forms of bamboo distributed throughout the world are classified into nonclump-forming and clump-forming types.

The nonclump-forming type includes *Phyllostachys, Semiarundinaria, Sinobambusa, Tetragonocalamus*, and some other genera distributed mainly in temperate and subtropical regions. This type of bamboo is characterized by monopodial rhizomes and culms; some buds of the nodes of the rhizome protrude through the earth every year to become the culm, whereas the buds at the apex of the rhizome become new rhizome creeping underground. Thus, bamboo culms emerge sporadically and are widely spaced. Most bamboos of this type are erect and long.

The clump-forming type includes genera like *Bambusa, Dendrocalamus, Schizostachyum,* and other genera that grow in the tropical regions. Characteristic of this type of bamboo is the fact that the larger buds at the lower portion of the culm located underground sprout directly above the ground and the sprouts grow into culms, forming a clump of culms with a short rhizome. The sprouting period of this type is much longer than that of the nonclump-forming type.

The distribution of these two types of bamboo clearly relates to the annual precipitation and temperature of areas where they grow. In general, high temperatures accelerate the growth of bamboo and low temperatures inhibit it, although the *Sasa* species grow rather well in the districts of low temperature.

Useful bamboo species commonly grow at the foot of mountains, on the riverside or riverbank, near farmers' homes, and so on. Most bamboo forests are cultivated in Japan, but some in the mountains have developed naturally over a long period.

The total bamboo-growing area is 123 000 ha, mainly distributed in the southern and western part of Japan (Kyushu, Shikoku, Chugoku, and Kinki regions). In the northern and eastern part of Japan, such as Hokkaido and Tohoku regions, the bamboo-growing area is small because of low temperatures; 98% of the total bamboo forest is on private land and is managed by farmers.

*Phyllostachys bambusoides*, locally known as *Madake*, occupies 42.5% of the total, and *P. pubescens* (locally, *Mosochiku*) constitutes 40.6%. Next is *P. nigra* forma *henonis* (common name, *Hachiku*) with 0.4%. *Pleioblastus* genus, which is used for fishing rods, handicrafts, and furniture, accounts for 5.3%, and many other species make up the remainder.

Bamboo is distinguished from *Sasa* by its habit of shedding its culm sheaths when the culms reach full size. In *Sasa*, they remain for 3–4 years. *Sasa* species are not as useful as bamboo, and they hinder the growth of trees; therefore, they are not discussed in this paper.

There are 5 genera, 52 species of nonclump-forming bamboos grown in the mild districts of Japan and 3 genera, 15 species of clump-forming bamboos in the warmer districts.

Some genera of bamboo and their characteristics have been reported (230, 263, 371, 401, 411, 412, 425, 442).

In Japan, *Phyllostachys* is usually characterized by caducous culm sheaths; large, cylindrical culms grooved on alternate sides; two (seldomly one) branches at a node; three stamens; and compound spikelets at inflorescence. It usually sprouts in spring (April–May); 8 species, 10 forms, and 14 varieties occur in Japan.

*Semiarundinaria* also exhibits caducous culm sheaths, but the culm is medium-sized. There are 3–5 branches at a node, the branches almost in bundles and cylindrical without grooves. Inflorescences are simple spikelets. Shoots appear in spring (May); seven species and eight varieties occur in Japan.

*Sinobambusa* is similar to *Semiarundinaria*, although it has long purplish hair at the nodes of new culms and side branches longer than one-half of its main branch. The culm sheaths are ciliate, and the internodes are long; outer glume is present. It sprouts in late spring (May–June); one species and one form occur in Japan.

*Shibataea* has caducous culm sheaths, undeveloped leaf sheaths, and 3–5 short branches at each node. The culms are slender and low, grooved on one side at the base of the internodes. This genus sprouts in spring (April–June); one species occurs in Japan.

*Tetragonocalamus* has caducous culm sheaths without appendages, square culm, and aerial roots at the lower nodes. It sprouts in autumn (September–November); one species occurs in Japan.

*Bambusa* has very short rhizomes and leaves that are not tessellate; it sprouts in autumn (October–November); four species and four forms occur in Japan.

## Propagation of Bamboo

Natural propagation of bamboo is mainly asexual, in the form of branching rhizomes. Asexual artificial methods of propagation include offset planting, culm cutting, layering, and grafting of rhizome cuttings. Sexual propagation is by use of seeds gathered after the bamboo has flowered. Asexual propagation has the advantage that the genetic quality of the planting material is known because it is the same as the source plant; its disadvantages vary for the different methods. Offset planting requires very hard work for the digging of the rhizomes; it entails considerable risk of damage to the roots and buds of the mother plant, particularly in clump-forming bamboos for which there is no sharp distinction between the rhizome and the culm. Of the other asexual methods, culm cutting is the only one that has had success thus far. It has proved suitable for the clump-forming types of bamboo that root easily but not for the nonclump-forming types. As a result, offset planting is widely used for propagation of the nonclump-forming types and culm cutting for the clump-forming types. Sexual propagation has the advantage of high success rates; its drawbacks are that the genetic quality of the seeds is less certain than with asexual propagation and that the seed is only available when the mother plant flowers and produces it (429, 437).

### Offset Planting

The planting material for offset planting may be the culm with roots and rhizome, the stalk with roots and rhizome, or just the rhizome. The selection of the rhizome is important in any of the methods.

The results of an investigation carried out in a *Phyllostachys bambusoides* forest showed that the diameters of culms in a clone of this plant varied from 4 to 13 cm and were closely associated with the age and diameter (Fig. 1) of the rhizome from which they grew. Rhizomes older than 3 years produced buds with reduced vigour and shoots that did not grow tall. The older the rhizomes, the less vigour in the buds. Also, the results showed that, of comparably aged rhizomes, those with larger diameters were better as planting material. The findings

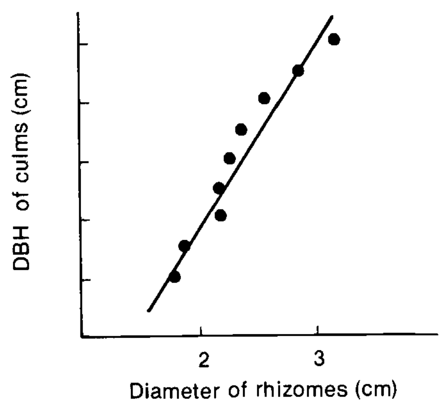


**Fig. 1.** *Relationship between diameter of culm and rhizome of P. bambusoides.*

indicated that planting material for *P. bambusoides* should be 2–3-year-old rhizomes having a large number of fibrous roots and golden buds. The rhizome sheaths should be used as an indicator of the age of the rhizome.

The length of the rhizome affects the survival of the shoot. The longer the rhizome, the more nutrients it contains to support the shoots. However, as the digging of rhizomes is very difficult, it is necessary to determine the minimum length needed to support the growth of the culm. In general, bamboo species with large-diameter culms require longer rhizomes, the length being about five times the basal girth of the culm. Rhizomes of *P. bambusoides*, if they are without the culm, must be at least 1 m to grow a mature bamboo shoot; the length for *P. pubescens* is 2 m. The survival rate is higher for rhizomes with culms.

Because nutrients released from the culm to the rhizome are always transported in the direction of the growth of the rhizome — a fact that was ascertained with radioactive phosphorus ($^{32}P$) — the basal part of the rhizome is preferred as planting material.

The rhizome should be cut carefully with a saw; it should not be dug during elongation, which, in nonclump-forming types, begins about 2 or 3 months after the growth of the culm shoot and continues for approximately 3 months. During this period, the nutrients that are stored within the rhizomes are absorbed in the process of growth of the new rhizome and are used up by the time the growth is completed. The rhizomes should be cut after the growth is completed.

When rhizomes are dug with the culm, the upper part of the culm and its branches are removed, but a portion consisting of several nodes and their branches is left as protection against the wind. The optimum months for offset planting in Japan are February and March, and the best time is when the buds on the rhizome show a slight swelling.

The greater the number of rhizomes planted per hectare, the earlier the bamboo forest becomes completely established and is ready for harvest. When the soil is fertile or the species is characterized by large-diameter culms, planting is less dense than it is with poor soil or small-diameter culms. For *P. bambusoides* and *P. pubescens* 400–500 pieces per hectare is recommended.

When planting the pieces, workers must be careful not to injure the junction of the culm and rhizome. The bamboo should be planted as soon as possible after being dug, and after the planting, irrigation should be applied.

Culm harvesting is usually not before 8–10 years after the planting even if 400 pieces/ha have been planted, because rhizomes elongate 1–3 metres a year, and the new culms sprout 1 year after on the growth of rhizomes.

**Propagation by Seeds**

In general, sexual propagation by seeds is feasible although not always practical because of the unusually prolonged flowering cycle for most species of bamboo. An interesting and curious phenomenon of bamboos is that some species die within 1 year after flowering, whereas other species survive but their vegetative growth slows down during flowering. Seeds can be collected from almost all bamboo species, but some species are more productive than others. In Japan, the seeds are sown in nurseries or in pots or planted directly in the field after germination at a temperature of 20–25 °C in a germination tester. *P. pubescens* seeds germinate 2–3 weeks after being planted in nurseries but take less time (3–5 days) in the tester.

Normally, it takes 10 years for nonclump-forming types of bamboo to reach a size suitable for harvest, but the time is shorter for the clump-forming types.

## Fundamentals of Bamboo Cultivation

Of the physiologic and ecologic activities of bamboos, the most important are the growth pattern of culm, translocation of nutrient, and the flowering and regeneration processes. An understanding of these processes permits bamboo cultivators to increase productivity by harmonizing the forest site with the physiology and ecology of bamboo. In Japan, much progress has been made in this area. The growth of culms and rhizomes has been described amply in other publications and reports. This paper summarizes investigations of the effects on productivity when different cultivation methods, stand densities, biomasses, fertilizer applications, etc. are used.

### Site Conditions

A good knowledge of the site conditions of bamboo forests is necessary. The minimum temperature should be considered; for instance, *P. bambusoides* does not grow well in areas where the temperature drops to lower than -5° C, and *P. pubescens* is better grown in areas where the temperature is never lower than -3° C and never higher than 33° C.

The best regions for vigorous growth of rhizome and cultivation of culm are those where there is a longer warm period in autumn than in spring so that nutrients accumulate in the rhizomes. In areas where there is snowfall, there is risk of injury to the bamboo in early spring when the snow tends to be greater in specific gravity and is a heavier burden for the plants. Rainfall should be 100 mm in the month when the shoot emerges and 200 mm or so during late summer (August–September) for the growth of the rhizomes. Total rainfall should be more than 1000 mm a year.

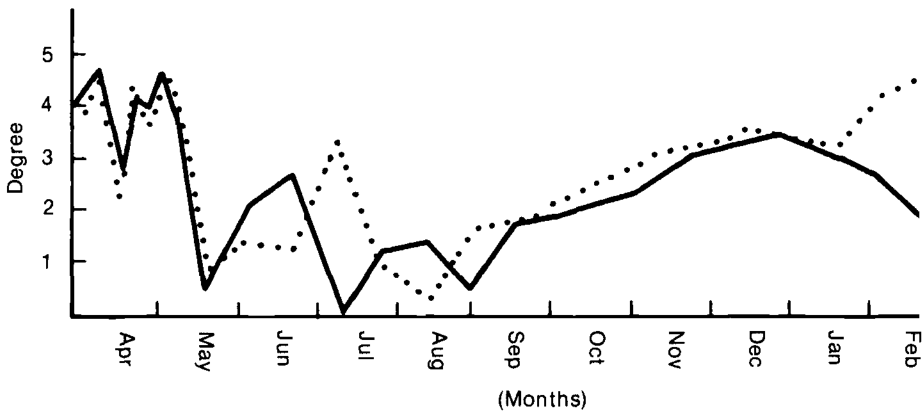


**Fig. 2.** *Seasonal changes of reserve starch in rhizome.*

Bamboos grow well in gently sloped lowlands or hilly districts, although steeper slopes are more suitable for *P. bambusoides* and *P. nigra* var. *henonis* than for *P. pubescens*. Fertile, well-drained soils with sandy loam or gravel are suitable for *Phyllostachys*. *P. pubescens* grows in highly humid soils, and it rather prefers soil mixed with clay. In contrast, *P. bambusoides* and *P. nigra* grow well in soil that is more or less sandy and moderately moist. *P. nigra*, which produces slender, black culms, and *P. nigra* var. *henonis* form. *boryana*, which has clear, dotted culms are suited to dry soils.

Soils with high moisture content and good water-holding capacity support bamboo well, whereas those with high volume : weight do not. Soils high in N, $P_2O_5$, $K_2O$, CaO, and $SiO_2$ promote the best growth, and the culms seem to grow very well even in acidic soils (pH 4.5).

## Growth of Bamboo Culm and Rhizome

A study of the relationship between rainfall and the elongation of the culm has indicated that rainfall promotes growth of the culm during greatest elongation but not toward the end of the process. In contrast, the growth of the rhizome is not influenced by rainfall even though the period for elongation of the rhizome is relatively long. The action of reserve nutrients must be considered as one of the factors that influences the growth of bamboo culm and rhizome. For example, the results of a study on the progress of reserve starch in the culm disclosed that the reserve starch in 1-year-old culms was greatest just before sprouting occurred; it decreased during the period of greatest growth of the sprouts and increased after the growth was finished; finally, the amount of reserve starch in the culm decreased again when the growth of the rhizome started and then gradually increased. The difference in culms younger than 1 year was that the reserve starch granules appeared earlier after sprouting began and increased progressively even during the growing period of the rhizome (Fig. 2). In other words, the consumption of the reserve starch in 1-year-old culms was greater than storage of starch during the growing period of the rhizome, whereas this phenomenon was not always seen in the younger culms. A similar tendency was observed in different-sized culms; for example, the larger the culm, the higher the amount of reserve starch. The amount of reserve nutrients in the rhizome decreased during the growing period and increased during the interrupted period of elongation. A close relation was clearly demonstrated between the elongation of both culm and rhizome and the amount of reserve starch.

A study of the vertical distribution of reserve starch at the beginning of January disclosed that the amount of reserve starch was greater in the upper part of the culm than in the lower part. Seasonal changes in the vertical distribution of the reserve starch in the *P. bambusoides* culm were in nearly the same category as those in *Pleioblastus pubescens*, a species of *Sasa*.

Other findings were that there are fewer leaves on 1-year-old culms than on older ones; the lumber from 1-year-old culms is soft; and 1-year-old culms are a significant source of productive nutrients although not widely used as such. The quantity of leaves was greatest for 2-year-old culms, whereas bamboos older than 3 years had decreased leaves inversely proportional to their increases in age. In contrast, the vertical distribution of the leaf amount in bamboos did not differ markedly at different ages, but the vertical position of the maximum area of leaves in 1-year-old culms or 5-year-old culms was commonly less than that for culms of other ages.

The relationship between the diameter (D) of culms and the number of leaves ($N_l$) was examined for 3-year-old *P. bambusoides* culm; the resulting equation was:

$$N_l = 2422.8D - 4625.4.$$

The relationship between the weight of both branches and leaflets ($W_{bl}$) and the diameter (D) of culms was also expressed by an equation:

$$\log W_{bl} = 1.4103 \log D - 0.6871.$$

The leaves are responsible for metabolism; therefore seasonal changes in the amount of defoliation provide essential information on the growth and existing amount of bamboo. Use of a litter trap has demonstrated an equilibrium in the seasonal growth of bamboos; that is, 53% of the annual amount of defoliation was noted during May–July and 30% of the annual defoliation was seen between October and November, the seasons of maximum growth of the rhizomes. The average annual amount of defoliation was half the existing amount of leaves — evidence of the theory that defoliation occurs in even years.

**Stand Density**

The optimum number of bamboos in a stand can be determined by observations of existing bamboo forests. Another method is the use of an index that is based on the diameter of the culms. The index for *P. bambusoides* is expressed by the equation:

$$\log \rho = 5.0326 - 1.9705 \log D$$

where $\rho$ represents the number of standing culms. Needless to say, the value also depends on the conditions of the soil, weather, topography, etc. (Fig. 3). The 35% density curve can be expressed by:

$$\log \rho = 4.5481 - 1.9705 \log D,$$

which provides the best density curve for *P. bambusoides*.

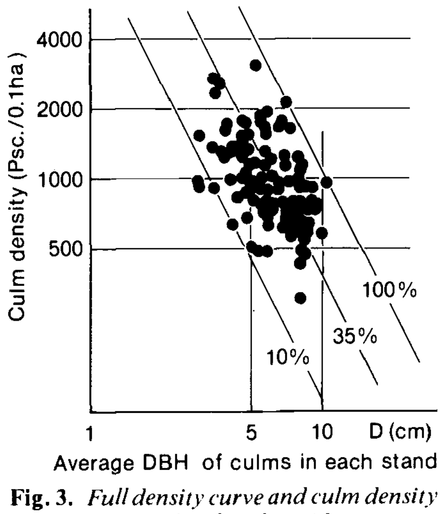


**Fig. 3.** *Full density curve and culm density index of P. bambusoides.*

Adequate stands promote productivity, but they can only be maintained by suitable selection of bamboo culm. Stands should be considered from viewpoints of ecology, physiology, and maintenance including, in order of priority, pest control in the bamboo forest; the use of fallen culms; the maintenance of random bamboo stands; and the value of 1–2-year-old culms, which are soft and not economically useful but are important in the forest for the continuation of bamboos. The majority of 2-year-old culms grow on the rhizomes, rich in reserve nutrients as well as reserve starch and nitrogen, and these culms, because of their plentiful leaves, play a functional role in the plant's metabolism. Thus, only culms older than 3 years should be cut.

The season recommended for cutting of bamboos is winter because the growth of bamboos is interrupted during this season. In addition, cutting should only be undertaken where the residual standing culms are sufficient to ensure continuation of the clump.

### Biomass in Useful Bamboo Species

There are few reports available that elucidate the productivity or biomass of, and annual production of, bamboo forests in respect to forest ecology. For this reason, the actual condition of bamboo forests in Japan has never been indicated scientifically, even though the productivity of bamboo forests has been empirically believed to be high. In this paper, the biomass of bamboo forest was estimated by the allometric method (Table 1).

Viewing the results obtained by the present research activities, one must conclude that tending bamboo stands or forests is essential, especially for the large-diameter bamboo forests so that productivity can be maintained and increased. The most important thing in managing bamboo forests is to ensure that the bamboos of good quality are properly spaced (Table 2).

### Fertilizer Application

A lot of inorganic nutrients are consumed by the bamboo during growth stages and propagation. The nutrients are supplied naturally through the soil or rain. If mineral salts are naturally abundant, fertilizer is not necessary, but sometimes fertilizer is needed for the improvement of soil conditions or the increase of yields.

Fertilizers should be applied about a month in advance of sprouting periods so that the effects appear at the time of sprouting and growth of rhizomes. The standard fertilizer used per hectare of bamboo forests is about 70 kg of nitrogen, 60 kg of phosphorus, and 80 kg of potassium; on shoot farms the amounts per hectare are 230 kg of nitrogen, 150 kg of phosphorus, and 200 kg of potassium. The application of silicic acid at 200 kg/ha improves results both in forests and in shoot farms. Much research has been done in this field (16–19, 287, 289, 405, 406, 409, 428, 438, 441, 444, 445, 446, 460).

## Bamboo Flowering

Flowering of bamboo varies among the species; some flower periodically and others do not; some die after flowering and others do not even though the culm is defoliated and weakened temporarily. There are several theories concerning the causes of flowering; they include the:

- Pathological theory, which postulates that flowering is brought on by destruction of bamboo through causal organisms like nematodes, fungi, insects, and parasites (Koide and Shirai);
- Periodical theory, which is that the cycle of bamboo regeneration, through asexual methods by rhizome and culm elongation, reaches maturity and results in flowering (Kawamura, Masamura, and Katayama);
- Mutation theory, which considers that bamboo regeneration through any methods of asexual propagation is mutation and brings about flowering of bamboos (Kasahara et al.);
- Nutrition theory, which proposes that flowering and fruiting are usually the results of a physiologic disturbance arising chiefly from the poor growth of the vegetative cells brought about by an imbalance of carbon-nitrogen ratio (Muroi and Ueda); and
- Human activities theory, which states that human practices such as building fires induce bamboo flowering.

All these theories need to be researched further as do the possibilities that meteorologic factors or conditions induce flowering. Another possibility is that continuous asexual propagation of bamboos does not deplete nutrient supplies

Table 1. Biomass of some bamboo species estimated by the allometric method (per hectare).

| | *P. bambusoides* | | | *P. pubescens* | *P. nigra* var. *henonis* |
|---|---|---|---|---|---|
| Site quality | Low | Middle | High | Middle | High |
| Stand density (pcs). | 22000 | 10000 | 8900 | 5100 | 13800 |
| Average DBH[a] (cm) | 4.0 | 6.0 | 7.1 | 9.3 | 6.6 |
| Height (m) | 8.0 | 12.5 | 16.7 | 13.2 | 12.6 |
| Culms (t dry weight) | 25 | 28 | 61 | 49 | 73 |
| Branches (t dry weight) | 14 | 10 | 13 | 9 | 12 |
| Leaves (t dry weight) | 7 | 7 | 6 | 5 | 9 |
| Roots (t dry weight) | 30 | 30 | 80 | 38 | 63 |
| Annual production of culms (t dry weight) | 4 | 5 | 6 | 8 | 6 |
| References | (428) | (428) | (460) | (405) | (409) |

[a]Diameter at breast height.

Table 2. Standard culm density retained after harvest (per hectare).

| Species | Site quality: High | Middle | Low |
|---|---|---|---|
| *P. bambusoides* | 4000–5000 | 9000–11000 | ≥18000 |
| *P. pubescens* | 3000–4000 | 4000–6000 | 6000–8000 |
| *P. nigra* var. *henonis* | 5000–6000 | 10000–12000 | 15000–20000 |
| *P. nigra* | 10000–13000 | 15000–20000 | 25000–30000 |

and, thus, could result in the accumulation of certain substances that bring about the production of flower buds. This possibility also should be studied.

A period in the generation of *P. bambusoides* covers a relatively long time, and death of both culms and rhizomes is brought on by flowering. However, sprouting of regenerated bamboos is anticipated before the culms and rhizomes die completely, and efforts should be devoted to effective utilization of the regenerated bamboo. For this reason in Japan, the ecology and changes in productivity brought about by flowering were investigated in both partially and fully flowering bamboo forests. As a result, it was found that the decrease in productivity of partially flowering bamboo forests was offset by nonflowering bamboo and growth of rhizomes, which produced sprouts of healthy bamboo. It was also found that the productivity of the fully flowering bamboo forest was arrested completely, although recovery of the stand was rapid when new bamboos were sprouted from seeds. It was shown that cutting the bamboos enabled them to regenerate more effectively. During these studies, the classification of regenerated bamboo was also attempted.

Fertilizer application promoted recovery of the basal diameter and length of culm of regenerated bamboos, but it did not increase the number of sprouts. After 3 years of fertilization, the culms were heavier than those of unfertilized bamboos, but the productivity was not increased substantially because the type of bamboo was only of limited utility. Several more years of fertilization were needed to obtain useful bamboo.

The application of fertilizer directly on the ground may have resulted in a delay in the absorption of nutrients, so an alternative method — spraying the leaves — was tried. The results were that regenerated bamboo in the control area was still producing sprouts even after 2 years of the experiment, whereas in other areas no sprouting was observed. In the area where the leaves were sprayed with alpha-naphthalic acetic acid plus urea, the sprouts of regenerated bamboo were abundant in the first year but were absent in the second year. In contrast, sprouting from new bamboos was not influenced in the first and second years of treatment, although differences were apparent in the amount of bamboo produced from the third year on. The yield from plants sprayed with alpha-NAA plus urea was greater than that from plants supplied with three nutrient elements spread directly on the ground. The latter, however, was better than that from plants sprayed with three nutrient elements, a treatment that was better than no fertilizer at all.

The comparative-recovery promotion test was carried out in four plots where nitrogenous fertilizer was applied. The spray of alpha-NAA plus urea on the surface of leaves was a better treatment than spray of urea alone, which was better than scattered urea on the ground, which in turn was better than no fertilization at all. The flowering ratio of the regenerated bamboo was found to be the inverse order of the recovery results.

The scattering of fertilizer on the ground did not affect the amount of leaves produced, but spraying the leaves increased their area. These results indicate that the spray of nitrogenous fertilizer on the surface of leaves effectively promotes the recovery of flowering *P. bambusoides* forests and that fertilizer applied directly on the ground improves only the recovery of rhizomes (188, 189, 194, 237, 286, 375, 428, 433).

## Genetics and Breeding

Studies on genetics and breeding in Japan have not yet progressed far enough to determine the causes of the factors involved in phenomena such as the flowering cycles and fruiting.

The pollen grains of some bamboo species show a wide variation (34.75–57.95 $\mu$m) in diameter, and those from regenerated bamboo that has developed subsidiarily from old rhizomes of *P. bambusoides* are generally smaller than those from flowering bamboo. The germination test of pollen grains of flowering or regenerated bamboo of *P. bambusoides* was undertaken on saccharose agar medium. The percentages of germination and the length of pollen tubes of *P. bambusoides* on agar medium soaked in solution were a little higher than on normal medium, although the reason is not completely clear.

Other studies on genetics include X-ray and colchicine treatment of seeds in attempts to make them polyploid but these have not been successful. The chromosome number of bamboo species propagated by monopodial type is 2n=48, although most tropical species that propagate by sympodial type have 2n=72.

Because electrophoresis techniques have been increasingly used in agriculture, forestry, medicine, and many other fields, studies of isozymes are increasing every year. In Japan, *P. pubescens* forests have been chosen as sample forests for variation experiments on isoenzymes. Results in this area are still at a preliminary stage (269, 270, 430, 447).

# Anatomy of Bamboo

W. Liese[1]

A brief description of the anatomical structure of the bamboo culm is presented as a basis for an understanding of the physical properties of bamboo. I looked closely at the parenchyma and vascular bundles and sorted out the correlation between several bamboo species and certain types of vascular bundles. I also examined the fibres in the internodes, reporting the average lengths of fibres found in some species of bamboo.

The properties of the bamboo culm are determined by its anatomical structure. The bamboos, belonging to the Gramineae, possess a primary shoot without secondary growth. The culm consists of internodes and nodes. In the internodes the cells are axially oriented, whereas the nodes provide the transversal interconnections. No radial cell elements, such as rays, exist in the internodes. The outermost part of the culm is formed by a single layer of epidermal cells, and the inner side is covered by a layer of sclerenchyma cells. Therefore, lateral movement of liquids is minimal, and the pathways for penetration of liquids are limited to the cross ends of a culm and — to a much smaller extent — the leaves at the nodes.

The gross anatomical structure of a transverse section of any internode is determined by the vascular bundles, their shape, size, arrangement, and number. The vascular bundles contrast the parenchymatous ground tissue, which is much lighter in colour. At the peripheral zone of the culm, the vascular bundles are small and numerous; at the inner part, larger and fewer. Within the culm, the total number of vascular bundles decreases from bottom to top, and their denseness increases correspondingly.

The culm consists of parenchyma cells forming the ground tissue and the vascular bundles composed of vessels, sieve tubes with companion cells, and fibres. The total culm consists of about 50% parenchyma, 40% fibres, and 10% conducting cells (vessels and sieve tubes). The percentage distribution shows a definite pattern within the culm, both horizontally and vertically. Parenchyma and conducting cells are more frequent in the inner third of the wall, whereas in the outer third the percentage of fibres is higher. In the vertical direction the amount of fibres increases from bottom to top, with the parenchyma content decreasing. The common practice of leaving the upper part of a cut culm unused in the forest is therefore a waste with regard to its higher cellulose content. The distribution of cell types within the culm is influenced by the type of vascular bundle present.

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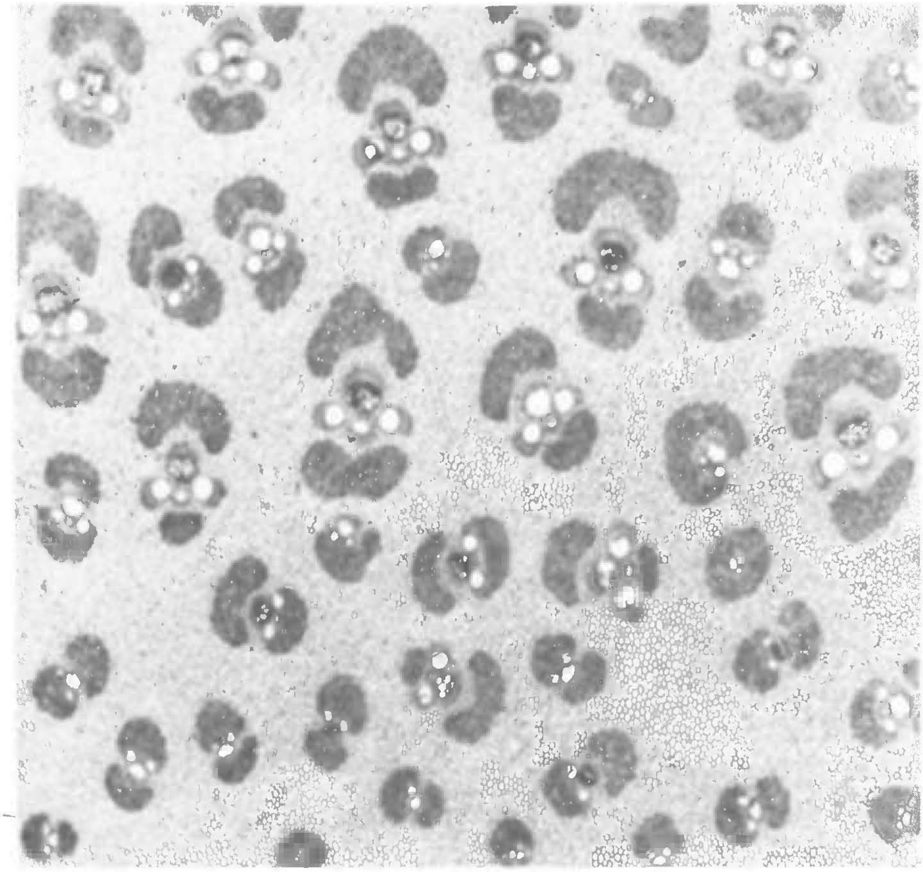

*Bamboo vascular bundle type IV.*

## Parenchyma

The ground tissue consists of parenchyma cells, which are mostly vertically elongated (100 × 20 $\mu$m) with short, cube-like ones interspersed in between. The elongated cells possess thicker walls, which become lignified in the early stages of shoot growth. The shorter cells are characterized by a denser cytoplasm and thin walls; the walls do not show lignification even in mature culms and retain their cytoplasmic activity for a long time — a fact that is demonstrated by the presence of peroxidase. The function of these two different types of parenchyma cells is still unknown. It may be investigated in relation to the unsolved mystery of the maturing process of a bamboo culm and its longevity. The relative high values of cold- and hot-water extractives of up to 10% are due to the large amount of parenchyma. The parenchyma cells are connected with each other by small, simple pits located on the longitudinal walls.

## Vascular Bundles

The vascular bundle in the bamboo culm consists of xylem with two large metaxylem vessels (40–120 $\mu$m) with one or two protoxylem elements and the phloem with thin-walled, unlignified sieve tubes connected with companion cells. The vessels are larger at the inner part of the culm and become small toward the outer part. This conducting tissue functions throughout the lifetime of a culm without addition of any new conducting tissue in contrast to hardwoods and softwoods with their cambial activity. In older culms, vessels and sieve tubes can become impermeable due to depositions of gum-like substances. Also, blocking of sieve tubes by tylosoid-like outgrowths occurs.

Both the vessels and the phloem are surrounded by sclerenchyma sheaths. They differ considerably in size, shape, and location, according to their position in the culm and the bamboo species. Most of the species have separate fibre strands on the inner or the inner and outer side of the vascular bundle. Intensive studies have led to the differentiation of four types of vascular bundles:

- Type I consists of the central vascular strand; supporting tissue only as sclerenchyma sheaths;
- Type II consists of the central vascular strand; supporting tissue only as sclerenchyma sheaths but the ones at the intercellular space strikingly larger than the other three;
- Type III consists of the central vascular strand with sclerenchyma sheaths and one isolated fibre bundle; and
- Type IV consists of the central vascular strand with small sclerenchyma sheaths and two isolated fibre bundles on opposite sides.

The presence of these vascular-bundle types in the bamboo species and their distribution within the culm correlate with the taxonomic classification system of Holttum based on the ovary structure. For example, type I alone is found in *Arundinaria* and *Phyllostachys;* type II alone, in *Cephalostachyum;* types II and III are found in *Melocanna* and *Schizostachyum*; type III alone is found in *Oxytenanthera*; and types III and IV are found in *Bambusa, Dendrocalamus*, and *Gigantochloa.*

The leptomorph genera (nonclump-forming) have only the vascular bundle type I, whereas the pachymorph genera (clump-forming) possess types II, III, and IV. Size and shape of the vascular bundles vary across an internode but also with the height of a culm. They become smaller from bottom to top. Within the nodes, an intensive branching of the vessels occurs with special analogical structures by which the passage of (invaded) air is prevented. Vessels run also through the nodal diaphragms so that all sides of the culm are connected at the nodes.

## Fibres

The fibres in the internodes occur as caps of the vascular bundles and in some species additionally as isolated strands. They constitute 40–50% of the total tissue. The fibres are long and taper toward the ends. Their ratio of length to width varies between 150:1 and 250:1. The length shows considerable variations both between species and within one species. The average fibre length of some species has been determined; for *Bambusa arundinacea,* it is 2.7 mm; *B. textilis,* 3.0 mm; *B. tulda,* 3.0 mm; *B. vulgaris,* 2.3 mm; *Dendrocalamus giganteus,* 3.2 mm; *D. membranaceus,* 4.3 mm; *D. strictus,* 2.4 mm; *Gigantochloa aspera,* 3.8 mm; *Melocanna baccifera,* 2.7 mm; *Oxytenanthera nigrociliata,* 3.6 mm; *Phyllostachys edulis,* 1.5 mm; *P. makinoi,* 2.5 mm; *P. pubescens,* 1.3 mm; *Teinostachyum* sp., 3.6 mm; and *Thyrsostachys siamensis,* 2.3 mm.

Various values have been reported for one and the same species. The reason is mainly that there is considerable difference of fibre length within one culm. Across the wall, the fibre length often increases from the periphery, reaches its maximum at about the middle, and decreases toward the inner part. Or the length may exhibit a general decrease from the outer part to the inside. The fibres at the inner zone of a culm are always much shorter (20–40%). An even greater variation (more than 100%) exists longitudinally within one internode. The shortest fibres are always near the nodes, the longest in the middle part. With increasing height of the culm, a slight reduction in fibre length occurs. Any measurement of fibre length has therefore to allow for this pattern of variation within the culm and should be based on representative samples.

The anatomical structure of most fibres is characterized by thick lamellated secondary walls. This lamellation consists of alternating broad and narrow lamellae with differing fibrillar orientation. In the broad lamellae, the microfibrils are oriented at a small angle to the fibre axis, but the narrow ones are mostly horizontally oriented. The narrow lamellae exhibit a higher lignin content than do the broader ones. A typical tertiary wall is not present, but in some taxa warts cover the innermost layer. Some species possess regular septate fibres, in which a horizontal lignified and lamellated wall (septum) divides the fibre lumen into chambers. The polylamellate wall structure of the fibres, especially at the periphery of the culm, leads to an extremely high tensile strength as demonstrated in the engineering constructions with bamboo culms.

# Preservation of Bamboos

W. Liese[1]

Bamboo's low natural durability means that the service life of structures made from it is often short. One way to extend its life is through processing and construction methods that minimize attack by fungi and insects. Conventional methods, like soaking in water, deplete the starch content of the bamboo and thus may reduce insect infestation. However, better preservatives and treatment techniques, if applied, will extend the service life of bamboo structures considerably, even in hazardous situations, and their increasing application throughout the world prove their economic value.

In its many uses, bamboo is generally exposed to attack by microorganisms and insects, and the service life of structures made from bamboo is mainly determined by the rate of attack.

## Service Life of Bamboo

Bamboo is liable to attack by fungi (brown rot, white rot, soft rot) and especially by insects (beetles, termites). Its durability depends on the climatic conditions and the environment, but untreated bamboo may have an average life of fewer than 1–3 years when it is exposed to atmosphere and soil. Under cover, it may be expected to last 4–7 years or more, depending on the nature of its use and the conditions. Under favourable circumstances, bamboo has been in service as rafters or frames for more than 10–15 years. In seawater it is destroyed by marine organisms in less than a year.

Bamboo has a low natural resistance compared with wood. Most of the observations on its durability are based on estimations made on full-sized structures. Few special service tests have been carried out thus far, and results from graveyard tests are still rare.

Some findings to date are that split bamboo is more rapidly destroyed than unsplit, the bottom portion of the culm has on average a higher durability than the middle or top portion, and the inner part of the culm is usually attacked earlier than the outer one, probably because of the anatomical structure. Also, laboratory experiments under controlled conditions have revealed that bamboo is more rapidly deteriorated by white rot and, especially, soft-rot fungi than by brown rotters.

The natural durability of bamboo is generally low, although it varies according to species. For example, *Dendrocalamus strictus* is less resistant to

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*Bamboo house in Bangladesh; preservation is much less costly than replacement.*

termites than is *Dendrocalamus longispathus*. Deterioration of bamboo by powder-post beetles starts as soon as the culm is felled. The beetles attack the bamboo for the starch, and the damage they cause — at least in the case of *Dinoderus minutus* — has been found to be proportional to the starch content of the bamboos. According to some investigations, bamboos harvested during summer are more rapidly destroyed than those felled after the rainy period, and, because the starch is depleted when bamboo flowers, flowered bamboo has a higher resistance to beetles. Its drawback is that it is also brittle.

Even for more-resistant species, a preservative treatment is widely regarded as necessary. However, it is seldom carried out. The reasons are the lack of knowledge about possibilities of bamboo protection; the lack of treatment facilities and preservative chemicals; the uncertainty about the advantages of bamboo preservation; and the lack of a market for treated bamboo.

In any consideration of bamboo preservation, a knowledge of the available methods, their advantages, and disadvantages is necessary, as is an understanding of the treatability of bamboo.

## Treatability of Bamboo

The treatability of bamboo is in general rather low. It differs according to species, age and moisture content of the culm, treatment method, and type of preservative. Most of these factors are influenced by the anatomical structure. A bamboo culm can anatomically be differentiated from wood by the following characteristics, which are important for the penetration of preservatives:

- The vessels run strongly axial; they are isolated from each other by the

*Bamboo boats are commonplace in Indonesia; the service life depends on contact with saltwater, sunlight, etc.*

parenchyma in the internodes and connected only in the nodes; they are very small at the periphery of the wall and become larger near the centre;

•A special layer of cells covers the wall outside and inside and retards penetration from both sides; and

•There are no ray cells in the bamboo tissue, facilitating an easy movement of liquids in the radial direction.

The penetration of liquid into a culm takes place preferentially in the axial direction from both ends through the vessels. To a small extent, movement is also possible through the intercellular cavity and the sieve tubes of the vascular bundles. Some penetration occurs at the nodes where the branches are cut. The penetration through the cuticula is slow. However, from the inner wall, diffusion is better than from the exterior. In the living culm the cuticula provides protection against water loss, and it is obvious that there would also be a low rate of diffusion in dead tissue. Even when bamboo is under pressure, the lateral penetration is small.

For maximum penetration, incising the inner part of the wall has been recommended, but because of the structure of bamboo, this method would probably improve treatability of only short pieces of bamboo. Boring axially through the normally impermeable diaphragm of the nodes has also been tried, the culm serving as a vessel for the preservative and the liquid penetrating the inside wall. In this case it must be ensured that the preservative is removed from the inside of the culm after treatment; otherwise it will be lost, and the results for absorption will be distorted.

For a satisfactory treatment of the tissue, it is necessary that the preservatives diffuse from the vessels into the surrounding fibres and parenchyma cells. The vessels occupy only a small portion — about 5–10% — of the cross section. Even when the vessels are completely filled, the bamboo culm can be destroyed by fungi or insects if the preservative does not diffuse into the tissue enough, the main portion of the culm being left untreated. Consequently, the preservatives must have good diffusion properties.

## Methods for the Protection of Bamboo

There are two kinds of methods that are used to increase the durability of bamboo: nonchemical methods, in which preservatives are not involved, and chemical methods. Whereas nonchemical methods have been used for a long time in the villages of many countries, chemical treatment on a larger scale is applied mainly in India and Taiwan. In Japan, prophylactic treatments and surface protection during processing are common.

Nonchemical methods are generally the so-called traditional methods. These are used quite often, although not much is known about their real effectiveness. They cost almost nothing and can be carried out by the villagers themselves without special equipment.

One such method is curing in which culms are cut at the bottom but are left for some time with branches and leaves on the clump (clump curing). Because the assimilation of the leaves still goes on, the starch content in the culm is reduced and as a result the durability against infestation by borers is increased. There is no influence on the resistance to attack by termites or fungi.

Another method is smoking. The culms are stored above fireplaces inside houses for some time so that the smoke blackens the culm. It is possible that this process produces toxic agents that lead to some resistance. Also due to the heating, the starch within the parenchyma cells may be destroyed. In Japan, bamboo materials are kept in a heating chamber at 120–150 °C for 20 min. This treatment is considered to be in some way effective against insect attack, although it may cause cracks — a possibility that would lead to increased susceptibility.

*Preservation of bamboo culms by pressure treatment in upright container.*

Whitewashing is a traditional treatment probably used more for its ornamental effect than for its preservative value. Bamboo culms and bamboo mats for housing construction are often painted with slaked lime ($Ca[OH]_2$), which may delay water absorption and, thus, lead to a higher resistance against fungi. But special investigations on this method have still to be carried out; among other things, they should show whether the strength of bamboo is affected by the alkaline. In Indonesia, bamboo mats are tarred and later sprinkled with fine sand. As soon as the sand clings to the mat and the tar is dry, whitewash is applied (up to four times). Plastering is also commonly done, by the people, using cow dung mixed either with lime or with mortar.

Soaking is commonly used in Asian countries. The freshly cut (green) culms are put into stagnant or running water or mud for several weeks. Because the specific gravity of the culms is less than 1, stones have to be put on the bamboos to keep them submerged in the water. Subsequently, the bamboo is dried in a shady place.

During the soaking period, the starch content of the parenchyma cells is reduced. The method is therefore said to improve the resistance against borers. This assumption, however, remains to be proved. It must also be emphasized that the method does not increase the durability against termites and fungi and that the submergence in water may lead to staining of the bamboos.

Much damage can be avoided by the use of simple construction methods such as placing bamboo posts on stones or on cement walls instead of putting them directly into the ground; the bamboo can be kept dry so that at least deterioration by fungi is prevented. It is strongly recommended that, in bamboo house constructions, the basement be made of concrete work or stones. A treatment with water-repellent formulations reduces moulds.

Methods using chemicals for preservation generally provide more effective protection than do nonchemical methods, but they are not always economic. Fumigation with methyl bromide or some other chemical is applied in Japan for insect control. Brushing and spraying are rarely done except for prophylactic purposes because these methods have only a temporary effect, reflecting the very low penetration of the preservatives. A prophylactic treatment may be advisable in bamboo depots and paper mills.

At times, bamboo that is to be used as piling for buildings is tarred and wrapped in palm-fibre ropes.

Another method is butt treatment in which the bottom part of a freshly cut bamboo culm with branches and leaves is placed in a barrel containing a preservative. The transpiration of the leaves, which is still in progress, draws with it the solution into the vessels of the culm. Cutting and subsequent handling, however, may allow air into the vessels at the bottom and reduce the suction effect of transpiration. Moreover, this method is possible only with rather short culms of high-moisture content. It takes a long time, and in most cases the vessels do not take up enough liquid to preserve the surrounding fibres and parenchyma.

The open-tank treatment is an economic and simple method with a good protective effect. Culms prepared to size are soaked in a solution of a water-soluble preservative for several days. The solution gets into the culm by diffusion through the ends and partly through the sides. Practical investigations carried out on the conditions for open-tank treatment indicate that immature bamboo allows much better penetration through both the outer and the inner skin than does mature bamboo. This effect may be correlated with the amount of lignification. Both the outer and the inner skin are permeable to some extent to preservatives during long soaking; however, the inner skin is a little more permeable than is the outer. Consequently, split culms can be treated more easily than round ones, and the use of split bamboo could reduce the soaking period by as much as one-half. Penetration and absorption of water-soluble preservatives are lower in freshly felled culms than in air-dried material. In air-dried culms, diffusion in the axial direction has been found to be about 20 times that in the transverse direction and radial diffusion is slightly more than the tangential. Diffusion through the inner wall is faster than through the outer part. It has also been found that the preservative solution should have a higher concentration for freshly cut bamboos.

Because water absorption in bamboo is generally slower than in treatable wood species, the soaking period has to be considerably longer than that for wood of the same dimensions; however the duration of treatment depends mainly on the kind of preservative chosen, the bamboo species, and the condition of the culm.

Using hot dipping or the hot and cold method can considerably reduce the time of treatment, and mechanical scratching of the outer skin may speed up penetration, especially for slow-diffusing preservatives.

The Boucherie method has proved effective for freshly cut material. The water-transporting part of the culm can be penetrated completely, and the treatment itself needs only few and cheap installations. In the classical form of the method, the preservative is forced by gravity from a container placed higher than the stem through pipes into the stem base. The higher the vessel is fixed, the faster is the penetration. It is also possible to hang the culm vertically and to scratch the inner wall of the top internode so that it acts as a reservoir for treatment. The internode has to be filled several times.

At the beginning of the Boucherie treatment, the solution, dripping from the top end, consists mainly of sap and has to be removed. Later, the solution can be collected and, after addition of new salts, may be used again. The treatment is finished when the solution at the dripping end shows a sufficiently high concentration of chemicals.

This method is improved if pneumatic pressure (air pump) is used. At the bottom of a container, a small, metal tube is fixed from which several other tubes lead to the ends of bamboo culms. The culms are fastened to the tubes by rubber cuffs. The preservative is forced axially through the culm by an air pressure in the container. Compared with the classical Boucherie method, this method can reduce the time of treatment from several days to 3–8 hours. Such Boucherie installations are easy to transport and could be used directly in the forest.

The treatment duration and its effectiveness depend mainly on the bamboo species, the moisture content of the culm, and the preservative used. A low initial moisture content results in a higher osmotic pressure of the parenchyma cells surrounding the vessels. Thus the water is withdrawn from the preservative solution inside the vessels, and a precipitation occurs, blocking the vessels. The best results of the Boucherie method are, therefore, obtained during the rainy season or after it; failures may occur during the dry season. Young, immature culms with a higher water content are more suitable for this method than are mature ones with less moisture. The kind of preservative, especially its precipitation, fixation, and swelling influence on the cell wall, is also of great importance. Preservatives with quick precipitation and fixation generally stop flowing through the culm in a relatively short time, so the vessels and pits become blocked.

Compared with the classical Boucherie method, the modified version is much quicker and thus more economic. Relatively simple handling and reasonable installation costs make this method suitable for many purposes. The costs of treatment, however, are still a deterrent for certain fields of utilization. It is also not applicable for all bamboo species, e.g., *Bambusa arundinacea*, which has thin walls, splits easily, and is thorny.

Pressure treatment of bamboo is carried out in some countries, both with water-borne preservatives and with creosote. However, it is expensive and in many cases not economic for material such as bamboo. Also there are not enough preservation plants in operation. Pressure treatment penetrates air-dried bamboo well but may cause cracks or collapse of round bamboo. Cracks or collapse not only reduce the strength of the culm but also lead to inaccurate results when the amount of absorbed preservative is measured. Cracks and collapse arise especially in thin-walled bamboos, so that only the thick-walled species should be treated in their round form. Generally, in round culms, the preservative solution penetrates mostly from the cut surfaces and nodes into the culm. Split bamboos show a much higher absorption and penetration than do round bamboos. Here the preservative can penetrate from the sides too, thus rendering the treatment effective. In both cases, however, it is necessary for the preservative to have the potential to diffuse into the tissue later.

## Economics of Bamboo Preservation

So far, not enough is known about the service life of treated bamboo; the available results have been obtained from field tests rather than full-sized structures. Reliable data depend on numerous factors like the method of treatment, kind of preservative, absorption, and penetration as well as on the specific condition. To make a treatment economic, the service life of treated bamboo should amount to 10–15 years in the open and 15–25 years under cover.

Similarly there is very little information available on the economy of bamboo preservation. Inasmuch as bamboo is a reasonably cheap and easily available raw material, its preservation must also be inexpensive. In some cases, therefore, physical methods like soaking in water are in use, even though they give only temporary protection. The open-tank treatment is recommended as the most economic method. In certain cases, the more expensive methods like pressure treatment are economic. However, due to the small number of preservation plants, the costs of treatment are increased because of transport of the bamboo from the forest to the plant. Promotional measures are needed so that consumers are made aware that higher initial expenses pay off by a much longer service life of treated material. With respect to economics, one must also take into consideration the replacement costs, which often amount to much more than the cost of the material itself.

Fire protection of bamboo could greatly reduce losses. However, the cost for such treatments is much higher than that for protection against insects and fungi. Therefore, at present, fire protection is not regarded as feasible.

## Conclusions and Recommendations for Research on Bamboo Treatment

Bamboo is abundantly available in Asia and widely used as a construction material. In spite of its many excellent properties, bamboo is liable to biologic deterioration. Although the culms themselves are reasonably cheap, the costs of repair or replacements, especially of a bamboo house, are substantial. Therefore, the prolongation of the service life of bamboo houses and other bamboo structures as well as the prevention of decay are of great importance for the people's economy. Any preservation of bamboo must be cheap, easy to perform, and readily available.

More attention should be given to improvement of house construction techniques. In several cases constructional methods can reduce the hazard of attack. In particular, the fungal deterioration of the bottom part of bamboo posts can be prevented if the posts are placed on stone or cement basements or pilings instead of being placed directly in the ground.

The benefit of nonchemical methods of preservation is still uncertain. It is therefore recommended that more information about their effectiveness be collected and special tests be performed. Only simple chemical methods are even worth considering because most villages are far from industrial centres, where technical installations could be effected without difficulty. For the treatment of bamboo posts, mats, and *tarjas*, the open-tank method is recommended. It does not need complicated technical installations and can be set up anywhere there is a demand. Butt treatment of bamboo culms is also advisable. The time needed for treatment to provide sufficient retention and penetration with the available preservatives should be investigated.

Chemical protection depends on the use of a suitable preservative in a sufficient concentration. The use of an unsuitable preservative or at an inappropriate concentration leads to failure and to a great distrust of chemical preservation. If treated bamboo is to be used outdoors in an unprotected environment, nonleachable preservatives are called for. As far as possible the preservative should not contain components poisonous to human beings and animals, because in tropical countries the necessary hygienic precautions are sometimes too difficult to be observed.

The introduction and promotion of bamboo preservation is a rather difficult task. The consumer hesitates to pay more for any treatment, especially if the advantages are not immediate. But, because preservation of bamboo, especially for houses, would strengthen the economy of the poor, government authorities must strongly support the beginning of bamboo treatment.

The following steps are recommended:

- Placement of treated and untreated bamboo samples in front of every forest district officer, ranger, etc. After a short time the villagers will notice the great advantages of treated material. The samples should be supplied from one institution where treatment has been properly conducted.
- Installment of open-tank basins at rangers' or similar offices so that treatment is under the control of the forest service;
- Provision of preservative free of charge, either through the forest service, the agriculture development corporation, or the forest industries development corporation as a contribution of the government to people's welfare;
- Encouragement of consumer responsibility for treatment of materials; and
- Establishment of an action group for bamboo preservation to collect information on the service life of bamboo structures; install untreated and treated samples; elaborate the treatment procedure; install open-tank basins; inspect the treatment works; and promote the use of treated bamboo.

# The Mechanical Properties of Bamboo Used in Construction

Jules Janssen[1]

This paper highlights a research program on the mechanical properties of bamboo, including tests on compression, bending, shear, etc., in short- and long-term loading. I studied the relationship between these mechanical properties and the moisture content of bamboo, the position along the culm, and the influence of nodes, through statistical analysis. The relationship between mechanical properties and biological composition was also studied. For example, one question I attempted to answer was does the tensile strength on the macroscale agree with the theoretical strength of the cellulose and with the percentage of cellulose. A mathematical model of a sclerenchyma cell is introduced, reflecting the geometry of the cell, the composition, and the properties of cellulose and lignin. This model indicates the capability of the bamboo to withstand strains and stresses. If data on bamboo can be fed into the model and if the model produces strains and stresses similar to those from actual tests, the model represents an understanding of the mechanical behaviour of bamboo. Based on my assessment of the mechanical properties, I designed joints that form part of trusses and tested them. Then, using the best joint, I tested trusses on a full scale. These tests pointed to specific research recommended for the future.

In 1974, I began a comprehensive research program on the mechanical properties of bamboo, particularly for structural uses in joints and trusses. Although the problem of durability of bamboos is also a major one, it fell outside my specific field of interest, as did bamboo as reinforcement in concrete.

My research was prompted by a request made by volunteers in developing countries. They asked for technical advice on how to build bamboo trusses for schools and warehouses. At the University of Technology in Eindhoven there was no one who could help them, but I was able to find some information from the 1880s in the files of the former Royal Dutch Indian Army. With this information some advice could be given, and because the information appeared to be useful to many more volunteers, it was published as a reprint. Since then, several hundred copies of it have been distributed. In addition, a similar English text has been prepared. Both reprints contain information on the use of bamboo in building and should be used as supplements to the well-known UN manual *The Use of Bamboo and Reeds in Building Construction.*

Thus, I became interested in bamboo and developed a research program on the use of bamboo in building structures, especially in trusses for roofs or bridges. My idea was that bamboo could play a bigger role in building than it has. Bamboo trusses need to be streamlined as has been the case with wooden

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trusses. A century ago every carpenter built a wooden truss like his father did, with too much wood and of unknown safety. Now wooden trusses are designed, calculated, and built on the basis of much research, with less wood and of a known safety. I hope to contribute to the streamlining of bamboo structures.

## Tests on Mechanical Properties

My research started with a study of the available literature (not reported here). Next, I ordered bamboo from the Philippines and equipped a laboratory that had 70% relative humidity and was kept at about 25 ° C. First, I carried out a series of tests on compression, bending, shear, etc. in short- and long-term loading, statistically analyzing the relationship between these mechanical properties and moisture content, position along the culm, and the influences of nodes. One immediate problem with tests of bamboo is that no agreed standards exist; in contrast these are readily available for timber. In the past, researchers postulated their own separate criteria and tests. Thus, comparisons of results are extremely difficult. To give bamboo an equivalent place among other building materials, one should promote both standardization of test methods and intensive investigation into the mechanical properties of bamboo and the physical and biologic influences on these.

### A Simplified Explanation of a Statistical Model

This research program started from an analysis of variances. The advantage of this statistical method is the fact that one can test moisture content and other physical or biologic factors together and calculate the influence of every single factor. For example one can test the influence of moisture content (4, 8, and 12%), node (N), and internode (I) on the compression strength using six specimens (one each for N and I at the three levels of moisture); the results are a linear model:

$$y = \beta_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + e$$

in which $y$ equals the estimated value of compression stress at failure; $e$ equals the random error; $\beta_1$ equals the constant, approximately the mean value; and $\beta_2 x_2 + \beta_3 x_3$ is equal to the contribution to the compression stress due to moisture content, the $x_2$ (for simple calculation) being 1, 0, -1, and $x_3$ being 1, -2, +1 for 4, 8, and 12% respectively; $\beta_4 x_4$ is equal to the contribution of (inter)node such that $x_4$ equals -1(node) or +1 (internode). Based on these x values and on the results of the actual tests (i.e., the ultimate stresses), the values of $\beta$ are (in N/mm²) $\beta_1 = 81.1$; $\beta_2 = 3.5$; $\beta_3 = 0.4$; and $\beta_4 = 2.3$. Their significance can be calculated as well, and then the ultimate stress can be estimated for each combination of influences. For example, the estimated compressive stress for 12% moisture content (MC) and node is:

$$y = 81.1 + 3.5\,(-1) + 0.4\,(1) + 2.3\,(-1) = 75.7\ \text{N/mm}^2.$$

### Influences on Mechanical Properties

When testing the mechanical properties of bamboo, one deals with a series of influences. Some are constant and some variable. In my program the constants were the species (*Bambusa blumeana*); the age (3 years old); the conditioning (conditioned as opposed to green); and speed of loading/deforming. Considered as variables were moisture content (4, 8, or 12%, in equilibrium with 30, 50, or 70% relative humidity); position along the culm (bottom, middle, or top); node or internode; form and size of the specimen;

and short- or long-term loading. It must be emphasized that the purpose of my tests was not to determine the mean strength of the bamboo but to determine which influences determine the strength.

**Compression**

Compression tests were carried out on full cylinders cut from bamboo stems. The variables taken into account were moisture content (MC) (4, 8, and 12%); height of the specimen (50, 100, and 200 mm); node or internode; the stems from which the specimens were cut (a necessary variable for the correctness of the model only); position along the culm (bottom, middle, or top); as well as several interactions.

The results of the tests are listed in Table 1. The P-value is the probability that any value could be greater than the critical value in an F-distribution; with 5% level of probability, only the factors with a P-value <0.05 are significant. These are the constant (obviously), the MC, the stems (not of interest to this study), the position along the culm, and three interactions (14, 16, and 18). These results indicated that not all 18 parameters were needed; therefore the model was simplified.

The results also indicated that the compressive stress increases with decreasing MC. The height of the specimens, as defined in these tests, was not significant nor was the node or internode — a finding in the studies by Atrops (24) and Limaye (220). The position along the culm was very significant, that is, the top portion was much stronger due to the greater number of sclerenchyma than was the bottom (220). Failure was due to splitting, i.e., an excess of

Table 1. Results of compression tests on bamboo cylinders.

| Factor and levels | Value of x | Estimated parameter $\beta$ (N/mm²) | P-value [a] |
|---|---|---|---|
| Constant | $x_1 = 1$ | 81.1 | *0.00* |
| RH (30, 50, 70%) | $x_2 = \frac{50-RH}{20} = +1,0,-1$ (respectively) | 3.5 | *0.00* |
| | $x_3 = 3x_2^2-2 = 1,-2,1$ (respectively) | 0.4 | 0.55 |
| Height (50,100,200 mm) | $x_4 = \frac{H}{50} - 2 = -1,0,2$ (respectively) | -0.2 | 0.91 |
| | $x_5 = x_4^2 = 1,0,4$ | -0.4 | 0.67 |
| Node or internode | $x_6 = -1$ or $+1$ (respectively) | 2.3 | 0.11 |
| Stems | $x_7 = -1,0,1$ | 3.5 | *0.00* |
| | $x_8 = 1,-2,1$ | 0.2 | 0.69 |
| Position along culm (bottom, | $x_9 = -1,0,1$ | 6.8 | *0.00* |
| middle, top) | $x_{10} = 1,-2,1$ | -0.6 | 0.32 |
| Interaction: RH and (inter) node | $x_{11} = x_2 \cdot x_6$ | 1.1 | 0.29 |
| | $x_{12} = x_3 \cdot x_6$ | 0.6 | 0.39 |
| Interaction: RH and position | $x_{13} = x_2 \cdot x_9$ | 0.9 | 0.46 |
| | $x_{14} = x_2 \cdot x_{10}$ | -2.3 | *0.00* |
| | $x_{15} = x_3 \cdot x_9$ | 0.6 | 0.48 |
| | $x_{16} = x_3 \cdot x_{10}$ | -1.1 | *0.01* |
| Interaction: height and (inter) node | $x_{17} = x_4 \cdot x_6$ | -2.4 | 0.09 |
| | $x_{18} = x_5 \cdot x_6$ | 2.3 | *0.02* |

[a] Significant P-values are italicized.

the tensile strain on the pectin holding the fibres together. If one finds this tensile strain, it might be possible to explain the compressive strength of the bamboo.

**Bending**

Bending is an important factor in building construction; therefore many reports on bending of bamboo are available, e.g., Limaye (220), Karamchandani (185), and Sekhar (358). I also carried out short-term bending tests on 25 full stems, free span 4.50 m, four-point bending test, at 12% MC. My results varied markedly, with the mean for stress at failure being 84 $N/mm^2$, a standard deviation of 26 and an E-value of 20 000, SD of 3000. Failure occurred not in the tensile strength of the fibres but in the shear strength of the pectin in the neutral axis of the stem and in the tensile stress of the pectin, transversal to the fibre, in the area with longitudinal compression. The mean shear strength was as low as 2.25 $N/mm^2$ in short-term loading and 1.01 in long-term (6 months to 1 year) loading. Preliminary results with long-term bending tests are similar, and although the data are as yet insufficient to describe the creep and the recovery, the long-term strength seems to be about 55% of short-term strength; i.e., $0.55 \times 84$, or 46 $N/mm^2$. This value fits fairly well with the results to date.

My plans are to go on with these tests in 1981 but to be more systematic, e.g., 30 days creep and 30 days recovery repeated, perhaps, five times at stresses of 40 and 50 $N/mm^2$.

For bamboo tests, a Burgers-model, as for wood, seems appropriate. The highly crystalline regions have the properties of a spring, whereas the amorphous lignin has the properties of a dashpot (202). Creep occurs because in the amorphous parts of the cellulose, the relatively weak hydroxyls move away from their positions.

Although it would be interesting to study the relationships between creep and crystallinity in wood and bamboo, the differences in crystallinity between wood and bamboo are smaller than the differences due to the method of investigation (325).

**Shear**

Shear is important in bamboo because it is the weakest point. Hardwood has rays, which make the fibres form a union, but bamboo does not. The fibres of bamboo are merely glued together by pectin. As early as 1922, Meyer and Ekelund gave an overview of the tension-, deflection-, and shearing-strength of beech, oak, pine, fir, and bamboo to demonstrate that bamboo is as strong as wood in tension and deflection but much weaker in shear. In their opinion, the shear strength of the woods is 20–30% of the respective compressive strength, but bamboo's shear strength is only 8% of its compressive strength. One may assume that the wood gains 8% shear strength from the pectin and the remainder (up to 20–30%) from the transversal strength of the rays.

Although the lack of shear strength is considered a disadvantage for the structural use of bamboo, it is a big advantage for the use of bamboo by farmers and other people in basketry, matting, and handicrafts in which split bamboo is used. In the use of bamboo in structures, shear strength is needed in bends and joints. When failure occurs during bending, it is not because of a shortage of tensile strength in the fibres but because of incohesiveness between the fibres, in which shear plays a role. In the construction of joints, holes are needed, and these introduce shear in the bamboo.

To measure the influence of moisture content (4, 8, or 12%); position along the culm (bottom, middle, or top); node or internode; and size of specimen (40,

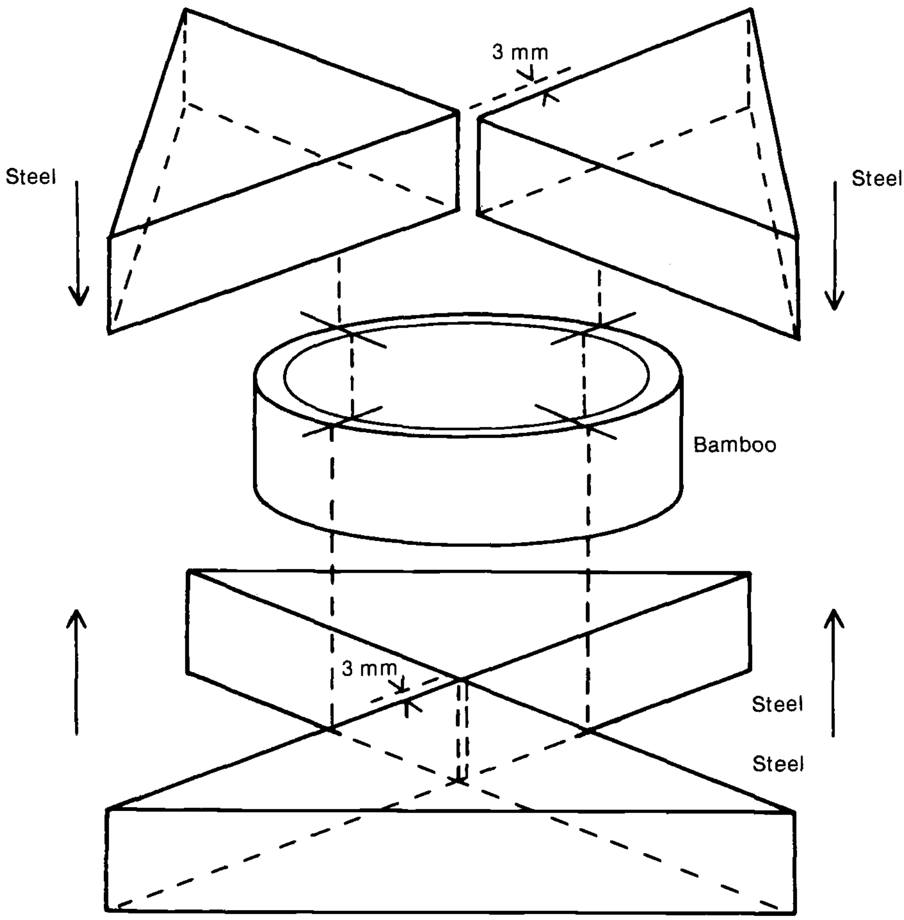


**Fig. 1.** *An unassembled view of specimen used in tests for shear strength.*

80, or 120 mm), I needed 54 specimens, which were made from three stems. The differences between stems were taken as a parameter, thus freeing the study from the influence of this factor.

The series of tests on the chosen design (Fig. 1) were an orthogonal scheme so that an analysis of variances was very easy (Table 2). At a 5% probability level, only the interaction between moisture content and position can be ignored. In other words, all the factors (moisture content, height of the specimen, [inter]node, and position along the culm) are significant; their influence on the shear stress is shown in Fig. 2. The significance of the moisture content fits with studies by Ota (302). It is commonsense: the strength of a material decreases with increasing moisture content. The best shear strength was at 80 mm height. Less strength at a shorter length may have been due to local irregularities, whereas less strength at a longer length is logical because the central part does not act as effectively as do the ends.

An internode appears to be better in shear than a node. In an internode all fibres run precisely along each other, but in a node they are interrupted by many vessels that cross them to reach the diaphragm inside the node.

Table 2. Results from shear tests.

| Parameter no. | Factors | F-values [a] Critical: $F^1_{36}$ ($\alpha$=0.05) =4.12 | Critical: $F^2_{36}$ ($\alpha$=0.05) =3.27 |
|---|---|---|---|
| 1 | Constant | *7392* | |
| 2 | Moisture content | *58* | *30.8* |
| 3 | | 3 | |
| 4 | Height of specimen | 0.7 | *9.6* |
| 5 | | *18* | |
| 6 | (Inter)node | *53* | |
| 7 | Culms | *22* | *26.3* |
| 8 | | *30* | |
| 9 | Position along culm | *18* | *9.8* |
| 10 | | 1.5 | |
| 11 | Interaction: moisture × (inter)node | 14 | *7.2* |
| 12 | | 0.2 | |
| 13 | | 0.4 | |
| 14 | Interaction: moisture × position | 0.0 | 0.9[b] |
| 15 | | 0.2 | |
| 16 | | 2.8 | |
| 17 | Interaction: height × (inter)node | 14.8 | *7.9* |
| 18 | | 0.9 | |

[a] Significant F-values are italicized.
[b] $F^4_{36}$ ($\alpha$=0.05)=2.65 (critical).

The last relationship, between shear stress and position along the culm, is one in which the shear strength decreases from bottom to top. In contrast to this finding, Atrops (24) found that the shear strength increases with decreasing wall thickness, i.e., from bottom to top. He argued that the percentage of sclerenchyma increases with decreasing wall thickness. Grosser and Liese (113) had similar findings. One reason for the sharp contrast with my results may be that Atrops, Grosser, and I studied different species.

*Conclusions:* The moisture content, height and form of the specimen, node or internode, and position along the culm all have a significant influence on the shear strength of bamboos. They should be defined in every researcher's series of tests and standardized, if possible, so that comparisons of results can be made.

My findings show that a shear area in a joint should be made from an internode because the ability to withstand shear stress in a node is less. It is true that the wall thickness in a node is greater than that in an internode, but this difference is not enough to make the shear strength per length of the culm better.

*What remains to be done?:* A study of designs for shear testing needs to be done, including those with only one shear area. Also a theoretical calculation of the shear strength of pectin and a comparison of this value with the shear strength found on the macroscale are needed as are long-term tests on shear and standardization of methods.

### Tension

Tensile strength and elasticity under tension are important qualities for bamboo used in suspension bridges (84) and as reinforcement in concrete.

Several authors have described methods to test the tensile strength of bamboo, but I met with many problems when trying to follow their prescriptions. The tensile strength of bamboo is rather high, e.g., 200–300 $N/mm^2$, but the E-modulus in compression transversal to the fibres is very low — a fact that causes considerable problems in grip. Also, bamboo has such a low shear strength that, in many cases, failure in tensile tests occurs by longitudinal shear or by transversal compression in the grip. My tests on tensile strength were similar to a method described by Atrops (24) but were few and are not reported here because the tensile strength is not important in trusses, my specific interest. Even in bamboos used for reinforcement in concrete, the tensile strength is not as critical as the durability and the bond. However, the relationship between tensile strength and the E-modulus is one key to the relationship between strength and structure. It is well known that the tensile strength and the E-modulus in tension are mainly determined by the percentage of sclerenchyma fibres, i.e., by the percentage of cellulose (Fig. 3).

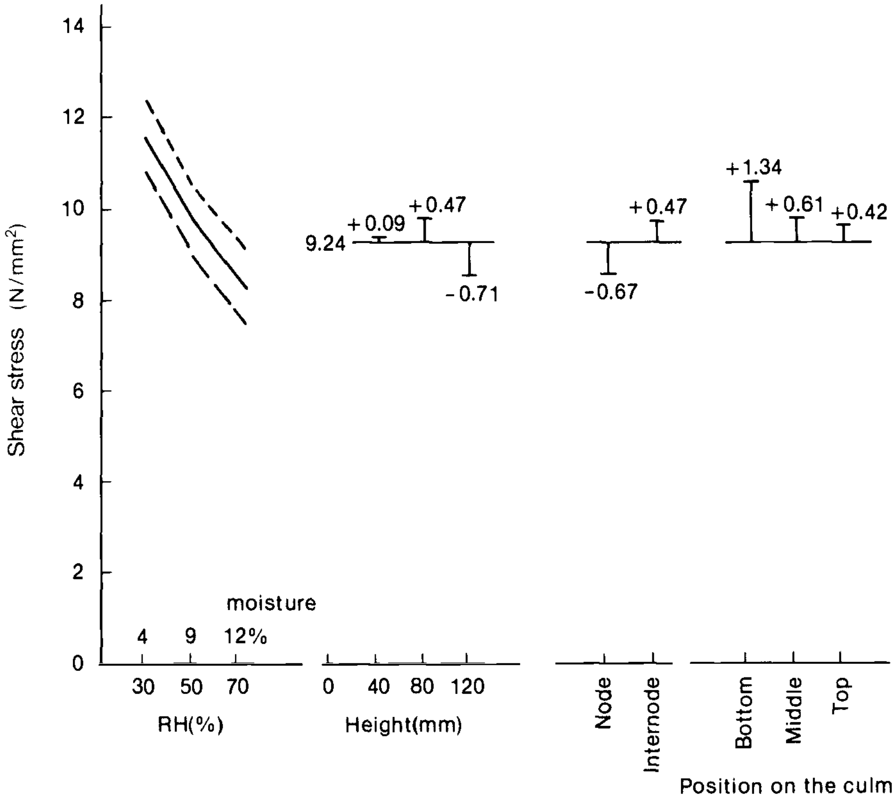


**Fig. 2.** *Estimated values of ultimate shear stress as a function of moisture content, with 90% areas, and influences of other factors.*

I tried to collect data from the literature on tensile strength together with data on the sclerenchyma or cellulose content for several species, but the results were not sufficiently comparable because the different authors used many test methods. A theoretical calculation of tensile strength for cellulose of 1500 $N/mm^2$ is possible (202). A sclerenchyma cell in bamboo contains 40% lumen, 50% cell-wall layer with cellulose fibrils parallel to the cell axis, and 10% cell-wall layer with cellulose fibrils in a spiral. In calculating the tensile strength, one neglects the lumen and the spiral layer; the remaining 50% consists of 50% cellulose and 50% lignin. Again, in calculating the tensile strength, one neglects the lignin. Then, the tensile strength of a sclerenchyma fibre is $0.5 \times 0.5 \times 1500\ N/mm^2 = 375\ N/mm^2$. Thus, a rule of thumb for the ultimate tensile strength in $N/mm^2$ is $3.75 \times$ the percentage of sclerenchyma fibres, which fits well with Fig. 3. Using the E-value of 70 000 $N/mm^2$ for the layers in the cell wall in which the microfibrils are parallel to the cell axis and assuming they constitute 50% of the layers, I calculated an overall E-value for the sclerenchyma cells of 35000 $N/mm^2$ ($0.50 \times 70000$). With this value, I derived a rule of thumb for the overall E-value of a bamboo culm: E-value ($N/mm^2$) = $350 \times$ percentage sclerenchyma. Applied to data from the literature, this rule of thumb provides an E-value for *Bambusa tulda* (45% sclerenchyma) of 15 750 $N/mm^2$ and for *Dendrocalamus strictus* (43% sclerenchyma) of 15 000 $N/mm^2$. The actual E-values are 19 300 (113) and 17 400 $N/mm^2$ (148) respectively. Although these figures are reasonably consistent, further study is needed.

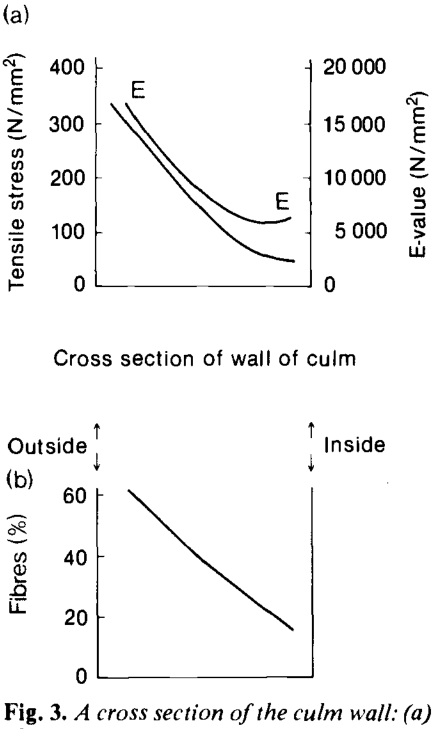


**Fig. 3.** *A cross section of the culm wall: (a) ultimate tensile stress and E-value for Phyllostachys pubescens (from Duff, 84) and (b) percentage of fibres for Phyllostachys makinoi from Grosser and Liese (113).*

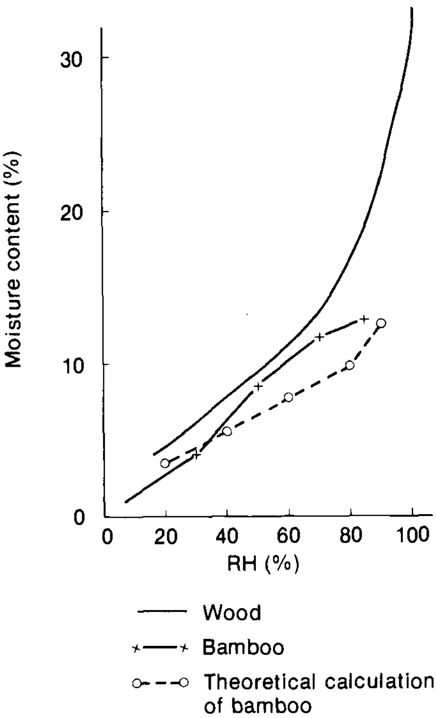


**Fig. 4.** *Relationship between MC and RH for wood and bamboo; the saturation points are at 100% RH.*

**Coefficient of Poisson**

I determined Poisson's coefficients for the outer skin, the cross section of the wall of the culm, and the inner side of the culm, in a pure tensile test, with strain gauges. My results were: outer skin 0.46; cross section 0.32; and inner side 0.34; these fitted well with Cox and Geymayer's findings (75) that Poisson's coefficient for bamboo is 0.317.

For timber, a value of 0.5 is common, approximating that for the outer skin of bamboo, which has a high silica content and a high percentage of cellulose. In contrast, the cross section and the inner side of bamboo, with its increasing portion of lignin, gives a value of 0.3, similar to that for steel and concrete. These facts present questions that need to be answered through further study and testing.

**Weight by Volume; MC versus RH**

It is rather simple to determine the weight by volume; it is more interesting to explain the determined weight. The specific gravity of cellulose is 1.58, and lignin 1.4. Assuming 50% of each and 44% materials (the remaining 56% being lumens and vessels), one can estimate weight by volume as $0.44 \times ([1.58 + 1.4]/2) = 0.66$.

The relationship between the moisture content in bamboo and the relative humidity of the air can be explained similarly (Fig. 4). If bamboo contains 55% cellulose, which, in turn, is crystalline (58%) or amorphous (42%) (325), the composition is 32% crystalline cellulose, 23% amorphous cellulose, and 45% lignin. The crystalline cellulose does not absorb any water. The amorphous cellulose does, and its absorption ratio is 1.85, which means that it absorbs 1.85 times as much water as native cotton (Table 3). This theoretical value fits well with actual figures (Fig. 4). In my opinion such explanations help in an understanding of mechanical properties and are a means to build bridges between biologic and mechanical researchers.

**Defects**

Bamboo seems to have more consistent properties than does wood because knots and slope of grain do not occur, but decay by rot and insects and splitting have a much greater influence in bamboo.

## A Model in Cell Mechanics

It is interesting to build a mathematical model of a cell. Based on the results of botanic and biologic researchers, such a model could explain the mechanical behaviour of bamboo (and wood as well). Such model studies have been published by Mark (232) and Schniewind and Barrett (352), but they simplify the cell wall to a flat layer, although a three-dimensional model is more attractive. My work on a mathematical model is not complete, but a brief look at it is necessary for fruitful discussions with botanists and biologists. As a basis for it, I collected data on the geometry and size of the cell and the cell wall.

**The Cell Wall**

The cell wall is a composite of fibres of cellulose in a matrix of lignin and hemicellulose. The composition is different for bamboo and wood, and a comparison of the two casts some light on their respective mechanical performance (Table 4 and 5).

Table 3. Theoretical calculation of the moisture content (MC) of bamboo.

| | | | | | |
|---|---|---|---|---|---|
| RH air | 20 | 40 | 60 | 80 | 90 |
| MC native cotton | 3 | 5 | 7.3 | 10.5 | 15 |
| Amorphous cellulose in bamboo MC(0.23 × 1.85 × MC native cotton) | 1.3 | 2.1 | 3.1 | 4.5 | 6.4 |
| MC lignin | 5 | 8 | 10.5 | 12 | 14 |
| (0.45 × MC lignin) | 2.3 | 3.6 | 4.7 | 5.4 | 6.3 |
| MC bamboo ([0.23 × 1.85 × MC native cotton] + [0.45 × MC lignin]) | 3.6 | 5.7 | 7.8 | 9.9 | 12.7 |

## The Cell

Any examination of the cells in bamboo is hindered by the substantial differences between botanic species, between fibres and other tissues, and between earlywood and latewood. Working with mean diameters and lengths introduces a big standard deviation, but it provides useful guidelines. The diameter of cells of common bamboos in $10^{-6}$m is 10–30; the length is 1000–3000 (217). Similar values for wood are diameter 33 and length 3500. Mark (232) suggested a model on how to calculate the overall E-value for a fibre, using the percentage of cell-wall constituents and establishing elastic constants.

The sclerenchyma cells are mainly responsible for mechanical properties, and so my model is limited to these. They can be characterized as thick-walled tubes, e.g., with an outside diameter of 0.03 mm, a thickness of 0.006 mm, and a length of 3 mm. The cell wall is a composite structure, built up with strong and stiff cellulose–microfibrils in a matrix of relatively weak and soft lignin. Each cell wall contains a number of layers, with the cellulose–microfibrils alternately nearly parallel to the cell axis and nearly perpendicular to the cell axis. I have

Table 4. Cross section of wall of bamboo cell, moving from the middle lamella to the lumen or from the primary wall through five secondary layers. [a]

| Layer | Orientation of fibrils | Thickness ($10^{-6}$ m) | Angle of fibrils [b] | Angle of fibrils [c] | Lignin content |
|---|---|---|---|---|---|
| Primary wall | – | 0.06 | – | – | – |
| Transitional lamella (1) | – | 0.12 | 50° | 35° | – |
| Transitional lamella (2) | – | 0.08 | 35° | 20° | – |
| Secondary wall (1) | Longitudinal | 0.60 | 2–5° | 5–6° | Low |
| Secondary wall (2) | Transversal | 0.11 | 85–90° | – | High |
| Secondary wall (3) | Longitudinal | 1.86 | 10–12° | 5–6° | Low |
| Secondary wall (4) | Transversal | 0.30 | 85–90° | – | High |
| Secondary wall (5) | Longitudinal | 2.70 | 10–20° | 10° | Low |

[a]There may be more than five secondary wall layers.
[b]According to Parameswaran and Liese (310).
[c]According to Preston and Singh (326).

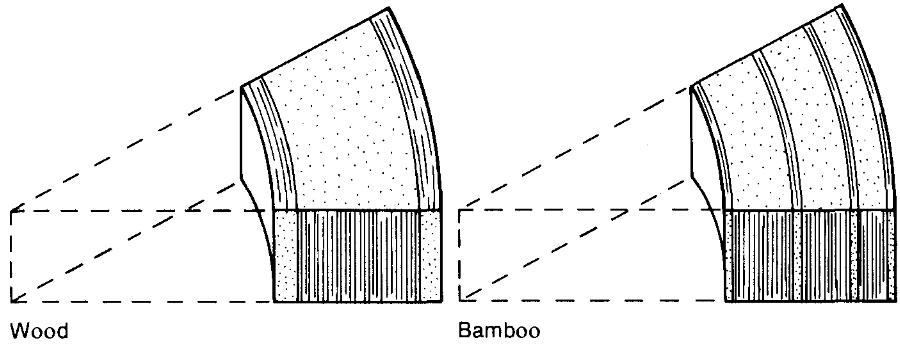


**Fig. 5.** *Cells of wood and bamboo.*

termed the layer with cellulose-microfibrils nearly parallel to the cell axis as "vertical" and the other layer, nearly perpendicular to the cell axis, as "spiral" (Fig. 5).

## Assumptions for a Mathematical Model

To build a mathematical model of a cell, I made certain assumptions based on the characteristics of a thick-walled tube under an axial stress. My assumptions were that no external forces are applied in the radial or tangential direction; the load along the x-axis is constant; stresses are rotationally symmetric with respect to the x-axis (no shear); the length of the cylinder is greater than the diameter and wall thickness; the plane cross sections remain plane; and the behaviour is elastic (no buckling). The equations for each layer of the cell wall are three constitutive equations and three equations concerning the equilibrium of forces. Using this model, one can calculate the radial displacement and the axial, tangential, and radial stresses.

## Numerical Example of the Model

I applied the mathematical model to two cells, one wood cell and one

Table 5. Cross section of wall of wood cell, moving from the middle lamella to the lumen, or from the primary wall through three secondary wall layers.

| Layer | Orientation of the fibrils | Thickness ($10^{-6}$ m)[a] | Thickness ($10^{-6}$ m)[b] | Angle of fibrils[b] | Lignin content[b] | Cellulose content |
|---|---|---|---|---|---|---|
| Primary wall (1) | – | – | 0.1 | – | High | Low (25%) |
| Primary wall (2) | – | – | – | – | – | – |
| Secondary wall (1) | Tangential | 0.12–0.35 | 1.0 | 50–70° | Low | – |
| Secondary wall (1-2) | – | – | – | – | Low | – |
| Secondary wall (2) | Longitudinal | 5 | 1–10 | 10–30° | Low | 50% |
| Secondary wall (2-3) | – | – | – | 20–30° | Low | – |
| Secondary wall (3) | Tangential | 0.08 | 1.0 | 60–90° | 10% | – |

[a]According to Kollmann and Coté (202).
[b]According to Siau (377).

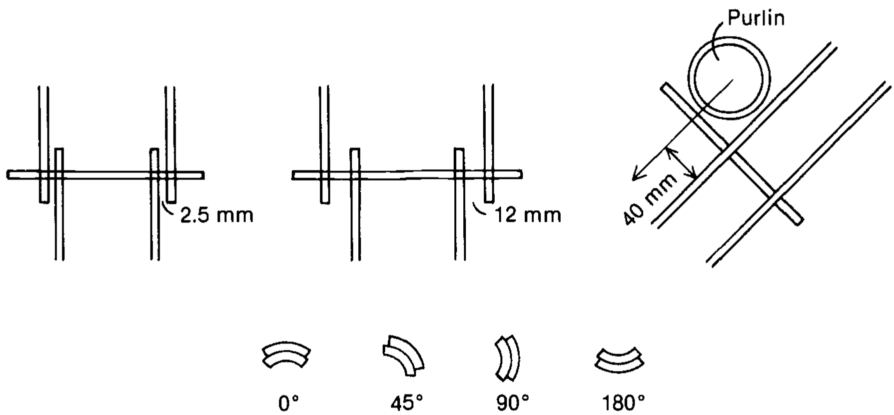


**Fig. 6.** *Tests on pins: the three details and position of the pin in relation to the force.*

bamboo cell. I assumed a constant interior radius of 0.010 mm and a constant exterior radius of 0.016 mm. So the wall thickness is always 0.006 mm, and the subdivision of this wall for wood is spiral layer 0.001 mm; vertical layer 0.004; and spiral layer 0.001. For bamboo it is spiral layer 0.0002 mm; vertical layer 0.0027; spiral layer 0.0003; vertical layer 0.0019; spiral layer 0.0001; vertical layer 0.0006; and spiral layer 0.0002. Next, I calculated values for E-modulus and coefficient of Poisson, each in three directions.

First I looked at the influence of these calculated values on the resulting stresses and displacements. The results comprised the radial displacement, the axial stress, the tangential stress, the radial stress, all as a function of the radius and all as a function of E and Poisson. The results indicate which values influence the deformations and stresses. Some values of E and Poisson have an enormous influence on deformations and stresses; therefore determining them is essential. In contrast, others have no influence at all, and one need not pay much attention to the estimation of them. In fact, however, these calculations are still just an introduction for calculations of the deformations and stresses in cells of bamboo and wood, assuming an external axial force. The calculated stresses have to be converted to the microfibrils with their respective angles with the cell axis, and then they have to be compared with the results of tests.

## Structures

My interest in the properties of bamboo was primarily in their application to bamboo structures such as pins (instead of steel bolts), joints, and trusses. A summary of my tests and results on such structures follows.

### Bamboo Pins

The strength of pins is determined by an interaction between the bamboo pin and the bamboo culms connected by the pins. To make things simple I tested the pins with steel "culms," assuming that this method selects the best pins in a similar way as would a method using bamboo culms. I studied the influences of three details; the position along the culm: pins from bottom, middle, or top; the circumference of the culm; pins from each quarter; and the positions of the pins, in relation to the force at 0°, 45°, 90°, and 180° (Fig. 6). Only the details were significant (F critical, $\alpha$ =0.05) (Fig. 7). I chose estimated stresses with 90% areas for the figure because a pin is stronger as the distance between the shear areas is smaller, due to the decreasing bending moment. The position of the pins had a slight positive influence at 0° and 45°, due to the hard outer skin of the bamboo culm in the tension area of the bended pin. Also the bottom portion along the culm may be better than the middle or top portion for placement of a pin, and a thin bottom portion is best. There seems to be no relationship with the percentages of parenchyma, sclerenchyma, and vessels. The influence of the quarters is rather small. A relationship between these differences and wall thickness cannot be found.

The results indicate that a bamboo pin can function as a connector, and a bamboo pin can be calculated at a 5% shear stress of $0.55 \times 23\,N/mm^2 = 12\,N/mm^2$. (This is a rough calculation, and the specimens, which were taken mainly from one culm, do not form a sample. Although the relationship 0.55 between short- and long-term results is valid for wood, it is still unknown for bamboo. The purpose of this rough calculation was to see whether bamboo pins were promising.) To maximize the strength of a pin, one must keep the shear

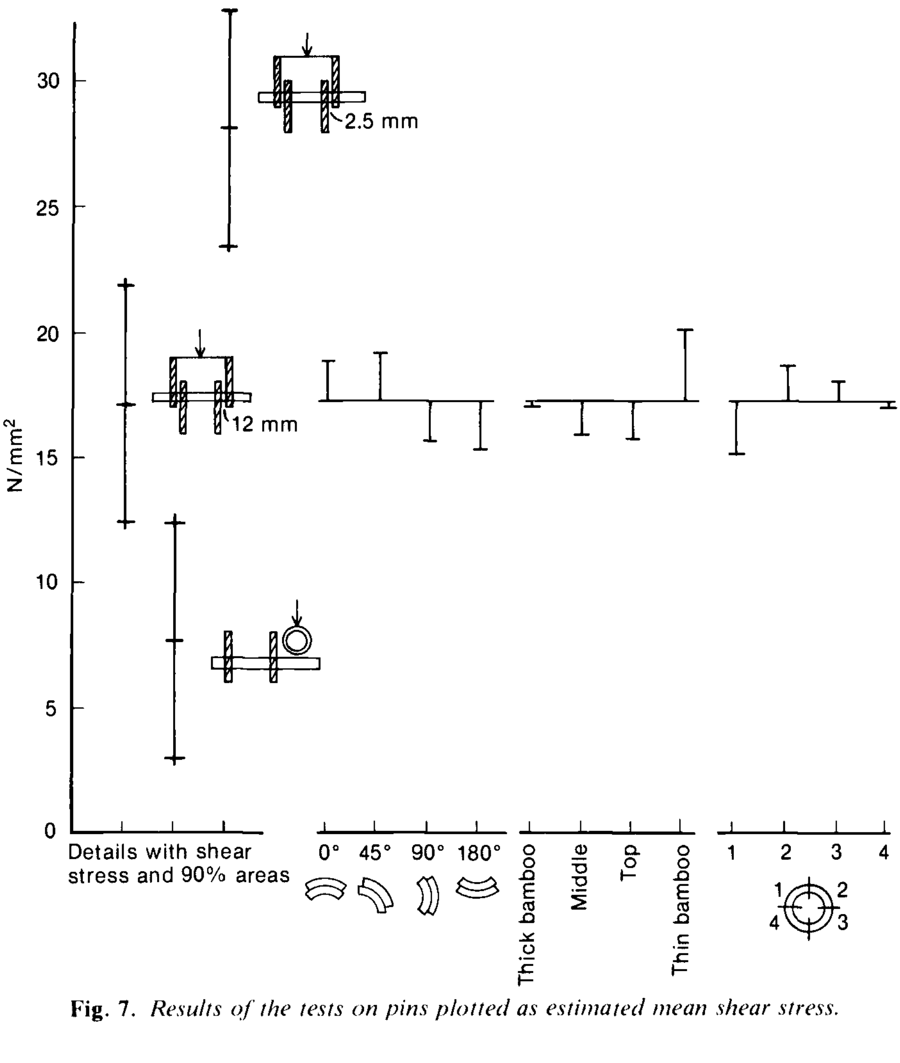


**Fig. 7.** *Results of the tests on pins plotted as estimated mean shear stress.*

*Test on truss, free span 8 m.*

areas as close together as possible. However, this procedure is not practical in the case of a support of a purlin (third detail). The distance between shear areas is half the diameter of the purlin, and this is a given. The deformations were great in my test with purlins, especially of 0° and 180°; 90° was best. As for the other two details, it is easy to place a bamboo pin in the position of 0° in a joint, and this is the best solution for practice.

The findings suggest that a bamboo pin is a promising connector in a joint instead of steel bolts; it is important to keep the shear areas as close together as possible; and in details with short-shear distances (e.g., a few millimetres), bamboo pins should be placed with their outer skin facing the force, but in support of a purlin, their outer skin should be parallel with the force.

*What remains to be done?:* Tests are needed on bamboo pins in bamboo culms, as are long-term tests; tests on pins with cross section; tests on the relationship between the strength of pins and the structure of the bamboo; and descriptions of a method to calculate bamboo pins on shear and bending.

**Bamboo Joints**

After the tests on mechanical properties, I directed my attention to joints that form part of a truss. I found descriptions of joints in the tradition of Southeast Asia, and in the literature. I also designed a few joints. In total I collected about 25 possible solutions for the same joint in a truss. From these, I selected four. The criteria for selection were: Does the joint look strong and stiff enough? Can it be made by people in a village with local materials and skills? And is it a simple joint? The four joints have been built and tested on a full scale, as if they were part of a complete truss. The distribution of forces in the joint was simulated with hydraulic jacks. The first tests failed, but several improvements were introduced and met with success. For each of the four joints, about 12 specimens have been made and tested, about 50 in all. During each test the forces were increased step by step until the joint failed; strains and deformations were measured as well, as a first step toward a better understanding of the mechanical behaviour of the joint. All the joints were made solely with bamboo and sisal rope. No steel bolts or other foreign products were used. The testing, however, was done with high-level Western technology of strain gauges, electronic equipment, and computers.

**Bamboo Trusses**

The joint that proved best was used in the construction of a truss, king-post type, 8-m free span. The diameter of the bamboo was 85–100 mm, the wall thickness 7–10 mm. As it was too difficult to test the truss in a vertical position, the truss was laid on the floor, with teflon on the supports to reduce friction losses. The load was brought on to the purlins by hydraulic jacks and a steel balance system. The load was applied in steps of 3.2 kN uniformly distributed (i.e., 0.4 $kN/m^1$). The immediate deformation of the truss was 50 mm; 15 mm was permanent deformation.

Creep was observed for 5 hours under a load of 18 kN (2.25 $kN/m^1$), which gives an extra deformation of 10 mm. After a few days of testing, the load was increased until failure of the truss, e.g., at 25 or 30 kN. Failure occurred not in the joint but in the bamboo itself, due to a compressive stress of, e.g. 70 $N/mm^2$. This result of short-term loading, observed three or four times, is not sufficient basis for technical advice.

Strains were measured at 50 points, and deformations at about 15 points. From these data, the behaviour of the bamboo truss was analyzed. With ICES-Strudl computer language, a model of the truss was built to predict the behaviour of the truss. The model was improved (e.g., with better data on the stiffness of the joints) until the calculated internal forces and external deformations agreed with those measured. The improved model was then used to find a better truss. Better means stronger, stiffer, less laborious to construct.

On the basis of this study a second truss has been built and tested, with the expected result. This procedure will be repeated not only with short-term tests but also with long-term tests as a means to study creep in a complete bamboo truss.

## Recommendations

Because bamboo should be exploited fully, one needs much more knowledge toward that end. Some areas where more studies need to be undertaken include:

- Durability. What is the natural durability of the various species? How can this be improved, preferably with local facilities? A classification of the species of bamboo, according to their natural or improved durability and to the use in building structures, is needed and could be similar to such classifications for timber.
- Mechanical properties. Tables listing allowable stresses are widespread for timber and are needed for bamboo. They should be based on a thorough knowledge of the botanic and physical factors with a significant influence on the mechanical properties; standardized tests based on this knowledge; and data on stresses to be used in building engineering practice.
- Relationships. Why are the mechanical properties as they are, based on the relationship with the biologic and chemical composition of bamboo? An understanding would be based on cell size, geometry, chemical composition; the distribution of sclerenchyma fibres along the culm, in node and internode, and in the thickness of the wall of the culm.
- Mathematical models. Models of cells and cell walls, based on the geometry of cells and cell walls, and the mechanical properties of cellulose, lignin, and pectin are needed. With such models, the mechanical properties on the macroscale can be explained or predicted.

# Properties and Utilization of Philippine Erect Bamboos

Francisco N. Tamolang, Felipe R. Lopez, Jose A. Semana, Ricardo F. Casin, and Zenita B. Espiloy[1]

Of the 48 bamboo species in the Philippines, 29 are erect and the rest are climbing; 10 of these species have been studied for the anatomic structure, pulp- and paper-making characteristics, fibre morphology, chemical composition, eating qualities of their shoots, physical and mechanical properties, new industrial uses, seasoning and preservation aptitudes. The results of these studies are presented in this paper. Of special mention is the high potential of bamboos for reinforced concrete, which has been confirmed by findings in India.

The properties and the utilization of Philippine bamboos have been well-investigated at the Forest Products Research and Industries Development Commission (FORPRIDECOM), College, Laguna. Although the studies are not comprehensive, they indicate gaps in knowledge that have to be explored by further studies and investigations. It is on this basis that FORPRIDECOM has aligned some project proposals.

The thousand-and-one uses of bamboos, which belong to the Bambusaceae tribe of the grass family, Gramineae, have long been known and established. From the lowly sticks used for fish and meat barbecues through the ribs for ubiquitous fans or the slats for sunscreens to the sturdy and practical so-called houses of bamboo, the bamboo's versatility is legend far and wide.

Bamboos constitute a large portion of the tropical forest in South and Southeast Asia, notably India, Sri Lanka, Burma, Cambodia, Indonesia, Laos, Malaysia, Papua New Guinea, Bangladesh, Philippines, and Vietnam. Genera found in these countries include *Arundinaria, Bambusa, Thyrsostachys, Gigantochloa, Dendrocalamus, Ceplorstachys,* and *Melocanna.* In temperate Asian countries, such as China, Japan, and South Korea, *Phyllostachys* and *Sasa* are the most common genera.

Bamboos are usually gregarious in two categories, namely: in extensive bamboo forests and in groups or colonies. Bamboos that grow together in the first category are usually confined within 15–25 ° of both sides of the equator, including the southern part of the People's Republic of China, Burma, Thailand, Laos, Vietnam, India, and Bangladesh, all in Southeast Asia. In contrast, only colonies of bamboos occur in Colombia, Peru, Chile, Paraguay, Bolivia, Madagascar, Mozambique, and Rhodesia.

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The Philippine archipelago, which is located 5–20 ° North of the equator, is located within the region most favourable to the growth of *Bambusa, Schizostachyum,* and *Dendrocalamus.* These species are generally scattered from north to south in the islands, and the region of central and northern Luzon (lying 15–20 °N) possesses an area highly suitable for the growth and development of bamboos.

Bamboos generally grow well in places that have temperatures ranging from 8.8 to 36 °C. There are exceptions; for instance, *Phyllostachys nigra* var. *henonis,* according to Uchimura (426), grows in Japan with a lower minimum temperature, and certain bamboo species in India have adapted to temperatures as high as 40° C. *Bambusa* has been found in Japan to be sensitive to temperature and light and grows faster during the night when temperature is high.

## Bamboo Utilization

At any rate, in the Philippines and in the rest of South and Southeast Asia, the versatility of bamboo is apparent from its many uses as containers, ornaments, toys, food supplements, musical instruments, structural components, and various industrial items.

Some centuries ago, the suitability of bamboo tools and bamboo fibres for making paper was demonstrated by Chinese artisans (245). As a result of recent fibre-dimension studies and improvements in paper-making techniques, various fine papers and their many adaptations can now be made from pulps of bamboos.

High-grade bamboo pulps can be used in the fine state for coated or uncoated book and magazine papers. Pulp from certain bamboos excels in the field of soft facial tissues and thin, India-type papers where opacity is required. *Tabashir*, precipitated within the culm internodes of many tropical bamboos, which largely consists of amorphous silica in a microscopically fine state, has been found to have excellent properties as a catalyst for certain chemical reactions.

Japanese scientists have demonstrated that charcoal prepared from certain bamboos has properties superior to those of charcoal derived from conventional sources for use in electric batteries (256). In India, bamboo charcoal is used for pharmaceutical purposes; many oriental jewelers use silica-charged charcoal from bamboos in preference to that from other sources. Too, from the white powder abundantly produced on the surface of young culms of Chinese bamboo, Chang (68) isolated, among other substances, a crystalline compound related to the female sex hormone. Piatti (319) reported the successful preparation of liquid diesel fuel from bamboo culms by distillation, and Yoshida and Ikejiri (469) found an aqueous extract of bamboo shoots superior to conventional media for the culture of certain pathogens (*Shigella* and *Brucella*). Also, the use of dried, mature bamboo leaves for deodorizing fish oils and the use of bamboo foliage as a supplementary source of forage have long been practiced in Asian countries.

In the Philippines, various useful and commercial articles are being processed from bamboo for domestic consumption as well as for export. The Philippine government, through the National Cottage Industries Development Authority (NACIDA), has made extensive efforts to improve the cottage industries, with bamboos as one of the major raw materials. NACIDA, too, manages the Technological Development Center in Marikina, Rizal, which is jointly financed by the Philippine and Japanese governments. Here, Japanese experts are assigned to test modern processing techniques, whereas other specialists from the Japan Overseas Cooperation Volunteers (JOCV) are assigned to the rural areas to undertake similar tasks and to promote better usage of bamboos.

Pulp and paper making is one of the most economically important aspects of bamboo utilization in the Philippines. In 1978, the domestic demand for pulp and paper reached about 500 000 tonnes, of which some 300 000 t were supplied locally — the rest being imported — to supply 19 pulp and paper mills. *Bambusa blumeana, Gigantochloa aspera,* and *G. levis* are suitable for kraft pulp, and *B. vulgaris* is suitable for wrapping paper and boxes.

Young shoots of some Philippine bamboo species are edible; in fact some excellent dishes are made from them and being served on Filipino tables. Not only the local Japanese and Chinese communities but also the Filipinos relish dishes from bamboo shoots; thus the cultivation of bamboos for shoot production is being encouraged. In Japan, about 10–20 t of bamboo shoots (408) are harvested from one hectare per year, valued at U.S. $1500–$3000. In Taiwan, production and exportation of bamboo shoots (preserved, dried in salt, and canned) are undertaken on a huge commercial scale. During the past 5 years, the annual turnover has exceeded U.S. $20 million (436).

Some species of bamboo attain tree size, as high as 25 metres; they are characterized by a hollow or, rarely, a solid jointed stem, called a culm. The culm may mature in 2–5 years after attaining full growth.

The erect species may be divided into two types — the clump-forming species (sympodial) and the nonclump-forming species that produce shoots singly from an underground stem or rhizome (monopodial). The former is characteristic of tropical regions; the latter, of subtropical or temperate regions.

In 1977 and 1978 in the Philippines, the total recorded production of bamboo culms was 787 229 and 426 108 pieces, respectively (317).

Bamboos are considered the most useful plants in the rural areas and are commonly called the "poor man's timber." The ease with which this forest product can be worked, its versatility, strength, and availability make it eminently suitable for domestic and commercial consumption.

The erect species may, for convenience, be divided into thick-walled and thin-walled bamboos with their own specific uses. For example, the frames of houses in the rural areas of the Philippines are constructed from the thick-walled bamboos; whole and unsplit culms are used for posts, beams, and rafters. When split and flattened, they are used as siding; when halved, as tiles for roofing and as eaves troughs. The thin-walled bamboos are split and woven into a coarse matting that is used for partitions, exterior walls, ceilings, and floors. Both have other uses, such as trellises for climbing vegetables and ornamentals, water pipes, blinds, furniture, toys, etc.

People from all walks of life find erect bamboos useful. Construction people use them for concrete reinforcement and scaffolding; fishing paraphernalia include bamboo rafts, fish traps, and fish pens, and in rural areas, whole bamboo culms serve as vessels for carrying, ferrying, and storing water. As a vegetable, the young shoots of some species are relished. In 1971, a Japanese Food Company established a commercial bamboo-shoot farm in Davao del Norte in Mindanao Island in the southern part of the Philippines (408). The species was *Dendrocalamus latiflorus* Munro; some 10 000 pieces of planting material, imported from Taiwan, were used in offset planting. The company started harvesting shoots for export to Japan in 1973.

In India, bamboo is an important raw material for pulp and paper making; however, Japan, Bangladesh, Thailand, Indonesia, and Taiwan utilize it much less for this purpose (359).

An interesting use of bamboo is for musical instruments (56), including horns, clarinets, flageolets, saxophones, flutes, piccolos, xylophones, and drums. A band called Pangkat Kawayan, which is composed of young Filipino girls and boys, has won international acclaim using such instruments; it has played in many cities in the United States, Australia, and some European countries, including socialist countries. A Roman Catholic Church in Metro Manila has a bamboo organ, which was patterned after Spanish models but was constructed to suit Philippine climatic conditions.

In the Philippines, there are 48 known species (426), of which 29 are erect and the rest are climbing. Some species have been introduced from other Asian countries. The commercially exploited species are *Bambusa blumeana* Schultes f. (*kauayan-tinik*), *Schizostachyum lumampao* (Blanco) Merr. (*buho*), *Dendrocalamus merrillianus* (Elm.) Elm. (*bayog*), and *Bambusa vulgaris* Schrad. ex Wendl. (*kauayan-kiling*). The most important among them is *B. blumeana* because of its innumerable uses, especially for house construction.

The climbing bamboos are of slight commercial importance and are, rather, a disadvantage because they form the most impenetrable thickets in the forest. They seem to be decidedly inimical to tree growth and are hard to eradicate once they have gained a foothold in an area.

## Research Results

### Anatomical Structure

Researchers in the Philippines have studied the anatomical structure of 10 Philippine bamboo species to determine the feasibility of identifying and differentiating the species (111). Of the 10 species, 8 are erect and 2 belong to the climbing type. The erect species are *Schizostachyum lima* (Blanco) Merr. (*anos*), *D. merrillianus, S. lumampao, Gigantochloa levis* (Blanco) Merr. (*bolo*), *Bambusa multiplex* (Lour.) Raeusch (*kauayah-china*), *B. vulgaris* var. *striata* (Lodd) Gamble (*kauayan-dilau*), *B. blumeana*, and *B. vulgaris*. The climbing species are *Schizostachyum diffusum* (Blanco) Merr. (*bikal*) and *Dinochloa scandens* O. Kuntze (zigzag bamboo).

In erect bamboo species, the transverse section of each representative internode from the base to the top portion and from the periphery toward the culm cavity shows vascular bundles of typical pattern and distribution. The vascular bundles vary in form, size, number, and shape. Four distinct vascular-bundle regions have been noted; these are peripheral, transitional, central, and inner. The peripheral region has smaller and numerous vascular bundles arranged more or less tangentially; those of the transitional region are incompletely formed. The transitional and central regions, which occupy the broadest area, show completely differentiated bundles. In the inner region, the bundles are generally small, simple, and often disoriented.

The horizontal and longitudinal variation of the vascular bundles within the whole culm of an erect bamboo is dependent on the culm-wall thickness. This means that the form, size, and pattern of the vascular bundles vary greatly, especially if there is a sudden reduction in wall thickness from the base, middle, or top internodes.

The structure of climbing bamboos, represented by the genera *Dinochloa* and *Schizostachyum*, is easily differentiated from the erect species. In the inner culm wall, the vascular bundles have two metaxylem vessels with extremely large diameters; a large and elongate-oval phloem; and only a small intercellular space. A characteristic feature is that the fibre tissue is limited to very small sheaths, and the fibre bundles are sickle-shaped.

Research findings indicate the feasibility of identifying and segregating the erect bamboos. However, between two closely related *Bambusa vulgaris* varieties, such as *B. vulgaris* Schrad. ex Wendl. and *B. vulgaris* var. *striata* (Lodd) Gamble, no significant anatomical differences exist, and the two climbing bamboos studied are similar in anatomical structure and difficult to segregate.

**Bamboo Pulp and Paper Making**

*Fibre morphology*: Table 1 shows the fibre dimensions and derived values of 13 bamboo species. Generally, the fibres are comparatively longer than those of the hardwoods (416, 417) and are less promising for paper making, based on their Runkel-ratio values, which should be equal to, or less than, 1 to be considered acceptable. Moreover, the fibres, which are stiff, produce sheets low in density and in overall strength. The fibres have high tear resistance but low tensile strength, based on their slenderness ratios and flexibility coefficients, respectively.

*Chemical composition*: The proximate chemical compositions of some Philippine bamboos (Table 2) reveal that Philippine bamboos are similar to other Asian bamboos in alcohol-benzene and hot-water solubles, lignin, holocellulose, and pentosan contents. However, the 1% NaOH solubility, ash, and silica contents are higher than in the bamboos of other countries (361).

Of the various bamboo species analyzed, whether of Philippine or foreign origin, *S. lumampao* contains the highest silica (6.4%). High silica content causes scaling during evaporation of the spent liquor during chemical recovery. *Bambusa vulgaris* and *B. vulgaris* var. *striata* (yellow bamboo) have the lowest silica contents of 1.5% and 1.3%, respectively.

*Cold-soda pulping*: Experiments with four bamboo species, some hardwoods, and softwoods showed that hardwoods are the most suitable for standard cold-soda pulping, as they are more responsive than the coniferous wood to the cold-soda process (282). Pulp yields of *D. merrillianus, Gigantochloa aspera, B.*

Table 1. Fibre dimensions and derived values of some Philippine bamboos.

| Species | Length (L) (mm) | Width (D) (mm) | Lumen width (l) (mm) | Cell-wall (w) (mm) | Slenderness ratio (L/D) | Flexibility ratio (l/D × 100) | Runkel ratio (2 w/l) |
|---|---|---|---|---|---|---|---|
| *Schizostachyum lima* | 1.67 | 0.022 | 0.004 | 0.009 | 76 | 18 | 4.50 |
| *Dendrocalamus merrillianus* | 2.16 | 0.014 | 0.006 | 0.004 | 154 | 43 | 1.33 |
| *Schizostachyum diffusum* | 2.00 | 0.021 | 0.007 | 0.007 | 95 | 33 | 2.00 |
| *Gigantochloa levis* | 1.80 | 0.022 | 0.006 | 0.008 | 82 | 27 | 2.67 |
| *Schizostachyum lumampao* | 2.42 | 0.014 | 0.006 | 0.004 | 173 | 43 | 1.33 |
| *Gigantochloa aspera* | 3.78 | 0.019 | 0.007 | 0.006 | 199 | 37 | 1.71 |
| *Bambusa arundinacea* | 1.73 | 0.022 | 0.006 | 0.008 | 79 | 27 | 2.67 |
| *Bambusa multiplex* | 1.36 | 0.018 | 0.002 | 0.008 | 76 | 11 | 8.00 |
| *Bambusa vulgaris* | 2.33 | 0.017 | 0.004 | 0.007 | 137 | 23 | 3.50 |
| *Bambusa blumeana* | 1.95 | 0.018 | 0.004 | 0.007 | 108 | 22 | 3.50 |
| *Phyllostachys nigra* | 1.86 | 0.019 | 0.006 | 0.0065 | 98 | 32 | 2.17 |
| *Bambusa tulda* | 1.45 | 0.200 | 0.005 | 0.0075 | 73 | 25 | 3.00 |
| *Bambusa vulgaris* var. *striata* | 1.66 | 0.021 | 0.005 | 0.008 | 73 | 24 | 3.20 |

Table 2. Chemical composition of some Philippine bamboos. [a]

| Species | Holo-cellulose (%) | Pento-sans (%) | Lig-nin (%) | Solubility in Alco-hol-ben-zene (%) | Solubility in Hot water (%) | Solubility in 1% NaOH (%) | Ash (%) | Silica (%) |
|---|---|---|---|---|---|---|---|---|
| *Gigantochloa levis* | 62.9 | 18.8 | 24.2 | 3.2 | 4.4 | 28.3 | 5.3 | 2.8 |
| *Schizostachyum lumampao* | 60.6 | 20.6 | 20.4 | 5.0 | 4.3 | 31.4 | 9.7 | 6.4 |
| *Gigantochloa aspera* | 61.3 | 19.6 | 25.5 | 5.4 | 3.8 | 22.3 | 4.1 | 2.4 |
| *Bambusa vulgaris* | 66.5 | 21.1 | 26.9 | 4.1 | 5.1 | 27.9 | 2.4 | 1.5 |
| *Bambusa blumeana* | 67.4 | 19.0 | 20.4 | 3.1 | 4.3 | 39.5 | 4.8 | 3.4 |
| *Bambusa vulgaris* var. *striata* | 63.6 | 21.5 | 25.9 | 3.7 | 3.9 | 24.7 | 3.0 | 1.3 |
| Range of values for 10 Indian bamboo species | – | 15.1–21.5 | 22.0–32.2 | 0.2–3.2 | 3.4–6.9 | 15.0–21.8 | 1.7–3.2 | 0.44–2.1 |
| Range of values for 10 Japanese, Burmese, and Indonesian bamboo species | 61.9–70.4 | 17.5–22.7 | 19.8–26.6 | 0.9–10.8 | 5.3–11.8 | 22.2–29.8 | 0.8–3.8 | 0.1–1.7 |

[a]Moisture-free basis

*blumeana*, and *Phyllostachys nigra* varied from 63.3% to 68.0%. The range compares with 50.2%–81.8% for 30 hardwoods and 73.5%–92.8% for coniferous woods. The bamboo pulps had low initial freeness but developed strength quickly when beaten. The studies showed that the hardwoods generally had stronger cold-soda pulps than did the bamboos or conifers.

*Experimental newsprint*: Quality newsprint has been produced from 80% unbleached *Endospermum peltatum* Merr. (*gubas*) neutral sodium sulfate chemimechanical (NSSCM) pulp and 20% bleached *S. lumampao* sulfate-pulp blend or 85% unbleached *gubas* cold-soda pulp and 15% bleached *B. vulgaris* sulfate-pulp blend (87).

*Pulping, bleaching, and paper-making experiments on B. blumeana*: By the single-stage sulfate-pulping process, *B. blumeana* chips are easily digested, and the pulps respond well to a standard three-stage bleaching process (88). Quality bond, airmail bond, onionskin, offset book, kraft wrapping, and bag papers can be produced from *B. blumeana*.

*Kraft-pulping qualities*: The kraft-pulping qualities of *G. levis, S. lumampao, G. aspera, B. vulgaris, B. vulgaris* var. *striata* (yellow bamboo), and *B. blumeana* were studied (417). These local species have higher ash (2.4–9.7%) and silica (1.1–6.4%) contents than do other Asian bamboo species, but they have less lignin contents than the Indian species do. Philippine bamboos were easily digested and produced bleachable pulp with permanganate numbers ranging from 13.0% to 18.2%; the screened-pulp yields ranged from 41.3% to 48.0%. Compared with foreign softwoods and Philippine hardwoods, the bamboos studied generally gave pulps with higher tear resistance but lower folding endurance, bursting strength, and tensile strength. The relative rigidity and the moderate length of the bamboo fibres were associated with the strength differences between bamboo pulps and the other wood pulps.

From the point of view of pulp strength, pulp yield, and acceptable level of silica content, the species *G. levis, G. aspera*, and *B. blumeana* (*bolo*, giant bamboo, and *kauayan-tinik*) appear to be suitable raw materials for kraft pulps.

*Wrapping papers from hardwood-bamboo sulfate pulp blends:* Paper made from the blends of bamboo (*S. lumampao, G. aspera, B. vulgaris*, and *B. blumeana*), 50% short-fibred hardwoods [*gubas, hinlaumo (Mallotus ricinoides* (Pers.) Muell.-Arg.), white *lauan* (*Shorea contorta* (Vid.) Merr. & Rolfe), *piling-liitan (Canarium luzonicum* (Blume) A. Gray)], and sawmill slabs had good tear resistance but low burst- and tensile-strength properties (258).

*Sulfate pulping of giant bamboo (G. aspera)*: The effects of some sulfate-pulping variables on the pulping of *G. aspera* showed that strength was not appreciably affected by changes in sulfidity from 17% to 33.9% (360), and varying the sulfidity from 17% to 25.5% did not affect the bleachability or the pulp yield.

The minimum total alkali that can produce a full chemical sulfate pulp is 12% (9.34% as $Na_2O$), and the maximum should not exceed 24%. In the studies, tear factor, folding endurance, and sheet density increased with increasing total alkali, and burst factor and tensile strength attained a maximum at 20–24% alkali. Kappa number and pulp yield tended to increase with a decrease in total alkali.

*Bag and wrapping papers*: *B. vulgaris*, pulped by the sulfate process, with an active alkali of 15.6%, gave a screened yield of 41.4% and permanganate no. of 15.0 (86). The pulp produced was characterized by very high tearing resistance but low bursting strength. The folding and tensile strengths were within the range of imported commercial kraft pulps that were tested and used as standards. Compared with commercial papers tested, the experimental bag and wrapping papers produced from this pulp had high tear resistance but low burst, fold, and tensile strength. However, the addition of beater additives, such as starch, guar gum, and locust-beam gum to the pulp furnishes, improved the burst, fold, and tensile strengths of the bag and wrapping papers. The resulting papers have strength properties superior to those of commercial papers tested and exceeded the U.S. federal specifications.

**Bamboo Shoots**

Quantities of shoots at three ages (7, 10, and 15 days after emergence) of six species of Philippine bamboos, namely, *Dendrocalamus merrillianus, Gigantochloa levis, G. aspera, B. vulgaris, B. vulgaris* var. *striata,* and *B. blumeana* were studied (109). The nutrient components such as protein, fat, ash, total carbohydrates, crude fibre, calcium, phosphorous, iron, thiamin (vitamin $B_1$), and ascorbic acid (vitamin C) were chemically analyzed. Results showed that age had no relation to nutrient contents. The shoots rich in one or more nutrients were made up of more than 75% water.

A taste panel of 12 selected members made a sensory evaluation of pickled bamboo shoots. Results of the taste test disclosed that 15-day-old *B. blumeana* shoots attained overall acceptability in colour, texture, and taste. Except for *G. aspera* shoots (7 days old) and those of *B. vulgaris* (10 days old), all the species may be acceptable for local consumption; the 7-, 10-, and 15-day-old shoots were deemed equally palatable.

**Physical and Mechanical Properties**

A knowledge of the physical and mechanical properties of bamboo is necessary for effective utilization.

To date, the physical and mechanical properties of three bamboo species, namely, *S. lumampao, B. vulgaris,* and *G. aspera* have been studied (89–91). Results have shown that:

•Strength properties either increase or decrease along the length of the culm, although, in general, increased strength is more evident at the top than at the butt and middle portions;

•Specific gravity tends to increase toward the top portion where the moisture is decreased;

•Fibres in both the nodes and internodes tend to become shorter toward the top

portion; the internodal fibres are longer than the nodal fibres; and
•In shrinkage, *S. lumampao* and *G. aspera* show similar trends where the butt portion of the culm has higher shrinkage values for thickness and width than do the middle and top portions, both at 12% nominal moisture content and oven-dry weight. In *B. vulgaris*, the middle portion of the culm has the highest shrinkage values.

A study on *B. blumeana* (92) showed that, for all engineering purposes, a culm about 30 cm in circumference (9.5 cm in diameter) when loaded at the centre on a span of 1.524 metres can support 0.50 t and when used as a post or column 1.219 metres can support 4.0 t. The thicker the specimen, the stronger it is. Shorter spans and shorter posts, in general, support greater loads, although this relation may not be an exact proportion.

**New Industrial Products**

*Bamboo parquet block*: The Forest Products Research and Industries Development Commission (FORPRIDECOM) developed a bamboo parquet block, which was granted patent no. 386 (utility model) on 24 August 1964 by the Philippine Patent Office. This utility model related to a commercial product of composite construction and materials in house and building construction particularly in parquetry as block flooring. As used in the specification, the term "parquetry" is applied to a flooring in which the strips (1.5 × 2.25 inches or 3.81 cm x 6.71 cm wide) are cut and laid out in a geometric pattern. At the right age and appropriate thickness, local bamboo species, particularly *D. merrillianus, G. aspera,* and *B. blumeana*, are ideal as raw materials for this utility model. And properly treated, they are strong and durable.

Compared with other parquets now in use and available in the market, the bamboo parquet block is cheaper because it is made up of an abundant local material and of veneer wastes. No intricate and expensive machinery is required for its manufacture. Warping, shrinkage, and swelling, easy wear, buckling, checking, etc., are not problems to the user because the construction is well-balanced and the slats are mounted to a stable base and securely glued.

*Laminated bamboo*: Utility model patent no. 43 of the Philippine Patent Office relates in general to an industrial product for construction materials, specifically to improved, novel, beautiful, strong, and durable laminated-bamboo sheets, panels, bonds, flitches, and other forms of construction materials for structural wood-decorative parts of houses, boats, and furniture.

In brief, the process is that bamboo culms are cracked, spread out, and flattened into sheets with suitable binding and filling materials; then the sheets are treated, combined, lapped, arranged, glued, treated, and pressed to the desired form; these are cut and trimmed to the desired size and shape and finally given finishing touches according to one's fancy.

*Bamboo strips for aircraft*: In 1956, the use of a bamboo-woven mat glued to wood or laminated to another bamboo mat for use as stress-skin covering for light aircraft was studied (214). The material was found to be relatively strong and its fatigue strength under bending stress was much higher than that of wood; the bond strength of bamboo to bamboo can be comparable to the bond between bamboo and wood.

**Bamboo-Reinforced Concrete**

In 1959, the use of common bamboo for reinforcing concrete beams was studied (328). The more salient findings were that:
•Bamboo reinforcement in concrete beams increased the load-carrying capacity

of members considerably above that to be expected from members of the same dimensions without reinforcement;

- Concrete members, reinforced with well-seasoned bamboo splints and treated with a dip coat of asphalt emulsion, better withstood loads than did equal sections with untreated splints; excessive treatment, however, materially lessened the bond between concrete and bamboo;
- When seasoned and untreated bamboo splints larger than 0.75 inch (1.9 cm) were used as longitudinal reinforcement in beams, there was some tendency for the concrete to develop horizontal cracks, especially when the percentage of reinforcement was high (the cracking of the concrete, which was probably caused by the swelling action of the bamboo, was of sufficient intensity as to destroy the load-carrying capacity of the members);
- The load-carrying capacity of beams, reinforced with bamboo, was increased by the addition of bamboo splints as diagonal tension reinforcement at sections where the vertical shear was high;
- The additional compressive area of flanges in Tee sections was not effective in bamboo-reinforced-concrete members; and
- A safe design stress is 3000–4000 lb./sq. inch (210.9–281.2 kg/cm$^2$) for concrete members reinforced with bamboo.

As reported by Mangahas[2], based on his trip to India, an effective arrangement for bamboos to be used as reinforcement in concrete is two bamboo strips, their inner walls facing each other and tightly fastened together by twine or a similar material.

**Durability, Seasoning, and Preservation**

Bamboos are very susceptible to attack by decay fungi and powder-post beetles, particularly *Dinoderus minutus* Fabr. (65). Of the species utilized for construction purposes, *B. vulgaris* is the most susceptible to infestation by powder-post beetle. Fresh, newly split, as well as seasoned, bamboos are susceptible to the attack by this beetle. Cut bamboos are commonly attacked by wood-decaying fungi (*Schizophyllum commune* Fr.).

Observations have indicated that the starch in bamboo contributes to its susceptibility to the attacks of beetles. It is the common belief of carpenters that flies swarming over green and newly worked bamboo are a sign that the particular bamboo is not durable. Soaking bamboo in seawater or running water for 2–3 months, as practiced in the rural areas, reduces its starch content and, consequently, lessens its attractiveness to the beetles.

For general construction purposes, only matured-bamboo culms more than 3 years old should be used. The bottom portion has been found, on average, to have a higher degree of durability than do the middle and top portions; the inner part of the culm is attacked sooner than is the outer wall.

Under ordinary conditions, the natural service life of bamboo, when used in contact with soil, is 1–3 years; when used indoors, 4–7 years. However, materials used in kitchens in rural homes where they are exposed to fumes of burning fuel have a service life extending from 10 to 15 years. Under marine-water conditions, bamboo has been reported to have a life expectancy of only 6 months.

Studies of Liese (215) on the natural-decay resistance of four Philippine bamboos showed that soft-rot fungus (*Chaetomium globosum* Kze.) caused the heaviest deterioration; a brown-rot fungus [*Coniophora puteana* (Schum)

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[2]A Filipino trainee sent to India in 1976.

Karst.] and a white-rot fungus (*Schizophyllum commune* Fr.) produced a moderate decay only. No distinct differences in durability among the four bamboo species studied were observed.

De Guzman (130) tentatively classified the resistance of some bamboo species to fungal attack; based mostly on percentage weight loss of the specimens after 4-month exposure, the findings were that *Dendrocalamus merrillianus* (Elm.) Elm. (*bayog*) was perishable; *Gigantochloa levis* (Blanco) Merr. (*bolo*), *Schizostachyum lumampao* (Blanco) Merr. (*buho*), *Gigantochloa aspera* Kurz. (giant bamboo), *Bambusa vulgaris* Schrad. ex Wendl. (*kauayan-kiling*), and *B. blumeana* Schultes f. (*kauayan-tinik*) were moderately resistant; *Schizostachyum lima* (Blanco) Merr. (*anos*) was resistant; and *S. zollingeri* Steud. (yellow *buho*) was very resistant.

Bamboo culms can be thoroughly dried in a dry, well-ventilated shed (65). Drying usually takes several months; the culms are laid horizontally on a rack that has supports at intervals of a few feet so that bending is minimized. When large quantities are dried, the butts and tops of the culms are placed alternately, then tied in bundles to prevent the development of new bends.

Culms that are bent are straightened. A fast process to straighten them is either to hold the curved portion over a charcoal fire or to apply a blow-torch to it. Care must be taken to prevent the culm from being scorched. Cooling is best accomplished by the application of a cold, wet cloth.

To straighten the bent green culms without application of heat requires from 2 to 4 months. This is done in a shaded area, the freshly cut curved culm either being weighted and suspended by the tip or being laid on a flat surface under pressure.

Immature culms lose moisture more rapidly than do mature culms but, during drying, the former develop cracks and collapse. The moisture content of a culm varies with height, i.e., the lower portion contains more moisture than does the upper part, with differences of 50% or more.

The treatability of bamboo with different preservatives is dependent upon its anatomical structure (216). Bamboo culm has nodes and internodes consisting of parenchyma cells and vascular bundles, which consist of vessels, thick-walled fibres, and sieve tubes. The orientation of the vessels, or in general, of the vascular bundles affects the penetration of the preservative. The absence of radial cells as in the rays of wood causes penetration to take place axially through the vessels and to some extent through the sieve tubes.

The internodal vessels are oriented parallel to the vertical stem, and the nodal vessels are connected with each other by pits. Likewise, vessels in the nodes are connected to those of the branches, thus providing horizontal transport of liquids. The treatability of bamboo takes place not only through the upper and lower ends, but also through cut branches at the nodes. From the points of entry, the preservative can penetrate the culm in both directions, toward the top and the bottom.

Dry bamboos are difficult to treat because of anatomical changes. In the drying process, the internodal vessels are filled with air; thus, penetration of preservatives must overcome surface tension and friction forces. Likewise, in the drying of parenchyma cells, the pit opening and cell walls are covered by certain substances that not only reduce the permeability of the parenchyma cells but also hinder the diffusion of the preservatives.

Green bamboos, in contrast, are generally easy to treat by diffusion on account of the axial transport of preservative inside the vessels. Suitable preservatives diffuse quite well from vessels to the parenchyma cells.

Preservative treatments of green bamboos with zinc chloride, ASCU, copper sulfate, boric acid, and borax applied by the Boucherie process and its different modifications; by soaking; by spraying; and by pressure methods have been investigated (65, 213).

The Boucherie process involves treating the freshly cut bamboo culm with its branches and leaves still intact and letting it stand in a receptacle containing the preservative solution. By this method, the solution is drawn to the top of the culm by means of transpiration through the leaves. There are three modified versions of this process. In the first, old bicycle-tire inner tubes are used as a preservative-solution reservoir, attached to the base of the bamboo culm in a horizontal position; the butt end of the culm is held at a slightly higher elevation than is the crown. The second utilizes the basal internodes as the reservoir for the solution and lets the bamboo culm stand in a vertical position; the time required for such treatment depends on the length of the culm, the preservative used, and the concentration of the preservative. For shorter lengths, one of the nodal-partition walls is bored through and filled with 16% zinc chloride and stored for 2½ months. The shorter bamboo culms can also be immersed in a tank, containing the same preservative for the same period. Such treatment provides higher concentration of preservatives to the inner layer of the culm, which, because of its high starch content, is very susceptible to powder-post beetles.

One pound of dry salt of zinc chloride absorbed per cubic foot of bamboo culm (16 $kg/m^3$), is an effective protection against fungi. The preservative is absorbed by the force of either gravity or the application of pressure (about 15–20 psi, 1.0–1.5 $kg/cm^2$) to the container of the preservative. The required pressure can be maintained with an ordinary bicycle hand pump. This method reduces treatment time and ensures complete penetration of the preservative in green bamboo.

Pressure treatment with ASCU and 50:50 creosote : fuel-oil mixture has proved satisfactory for split, dry bamboo but unsatisfactory for round and split green bamboo.

Soaking split and unsplit bamboo culms in saltwater for 8 weeks has been claimed effective in controlling beetle infestation, and immersion of split and unsplit bamboo pieces in 20% boric or borax solution for 24 and 48 hours, respectively, has been shown to prevent beetle attack.

Spray treatment of split or whole sections of bamboo with 5% DDT or BHC in kerosine was found effective against powder-post beetle infestation. This prophylactic treatment of newly felled bamboo provides temporary protection (for a few months) and is particularly useful in the forest while the bamboo is awaiting transportation.

At present, pressure methods are not widely practiced because of their cost, which makes them uneconomic for inexpensive materials like the bamboos. Besides, there are very few preservation plants that can handle pressure treatment.

To absorb sufficient preservative solution during pressure treatment, bamboos must be thoroughly air-dried; the method is not regarded as suitable for the thin-walled bamboos because cracks and collapse are likely to develop and to impair the strength properties of the culm. It is, therefore, necessary that only thick-walled species be pressure-treated.

Far more satisfactory results can be obtained with split bamboos because the preservative solution penetrates not only through the ends but also through the sides. Trials made on air-dried, round and split *B. vulgaris* with water-borne preservatives (Wolman CB at 6%) and creosote : fuel-oil mixture (70:30 ratio) showed an average absorption of 1.07 lb. dry salt/cu. ft. and 12.60 lb./cu. ft. (17.14 kg/m$^3$; 201.85 kg/m$^3$) respectively. The treatment schedule was a 30-minute initial vacuum at 25 inches Hg (0.85 kg/cm$^2$), a 1-1.5 h pressure period at 150 psi (10.55 kg/cm$^2$), and a 30-minute final vacuum at 25 inches Hg (0.85 kg/cm$^2$). The absorption data were obtained from split bamboo culms.

# The Angklung and Other West Javanese Bamboo Musical Instruments

Elizabeth A. Widjaja[1]

Several bamboo musical instruments (especially the *angklung* and *calung*) are supposed to have originated in West Java, because one may still find them in the remote areas inhabited by primitive natives like the Baduy in South Banten. There are more than 20 kinds of bamboo musical instruments, but only a few of these are still widely used now. The species of bamboos used in musical instruments in West Java are *Schizostachyum blumei, Gigantochloa* aff. *atter,* and *G. apus.*

The importance of bamboo musical instruments in the life of Sundanese (namely the inhabitants of West Java) is self-evident from their widespread use and cultural function. Bamboo musical instruments have been in Java since before the Hinduism period; in Borobudur temple (built about 8th century), one can observe depictions of the *calung* and *gambang.* It is presumed that the development of bamboo musical instruments has a close relation to the Polynesian migration before the Christian era. The long history is one of the reasons that bamboo musical instruments like the *angklung, calung, suling,* and *celempung* are so well-developed and widespread, understandably, under different local names.

Some of them (especially the *angklung* and the *calung*) are supposed to have originated in West Java; one may still find them in remote areas inhabited by primitive natives (like the Baduy in South Banten of West Java). The Sundanese used bamboo as material for musical instruments in honour of Dewi Sri, goddess of rice and agriculture in Javanese mythology. The melodious sound produced by the graceful and slender and beautifully constructed instruments is believed to express appropriately the cheerful character of the Sundanese people.

In West Java there are more than 20 kinds of bamboo musical instruments. They can be divided into three groups according to the methods used in producing the sounds:

- Idiophones (grating or hammer instruments), which include the *angklung, calung, gambang, rengkong, karinding, goong, guyon bolon, gangsing, kunclung,* and *kohkohl*;
- Aerophones (aero instruments) which include the *hatong, suling, taleot,* and *kolecer*; and
- Chordophones (string instruments), exemplified by the *celempung.*

Only a few of these are still widely used now.

The *angklung* typically consists of two, three, or four separate bamboo

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segments, usually tuned to as many octaves. The upper parts of the segments have been partly removed to about half their lengths so as to form a sort of tongue, and they are closed at the bottom by a node. They are suspended vertically but capable of limited movement horizontally inside a bamboo frame. Their bottom ends are hampered in their movements by means of small protuberances, which can slide to and fro for a short distance inside a slit made in the bottom frame tube. The bamboo tubes produce sounds when the instrument is shaken. The sound is curiously bright. The air-column in the tubular part of the mobile bamboo segments produces, when being blown, the same tone-pitch as the entire segments when being shaken.

The *angklung*, as a musical bamboo, went through several changes of functions in conformity with the historical development of the country. Even today the South Banten Baduy people have a custom of shaking three or four *angklungs* at the finish of the work upon the *huma serang* or the sacred arable land. According to the folklore, the *angklung* was a musical instrument of agricultural festivals. It was also used during festivities and to arouse the fighting spirits of soldiers. Long predating the arrival of Westerners in Indonesia, it was suppressed by the Dutch because it could influence the soldiers to rebel against colonial power. In the 1920s it was a toy for children, and by the 1930s it was degraded as a crude instrument played by beggars to attract the attention of passers by. It was then that a local musician, Daeng Sutigna of Bandung, started his efforts to resurrect the *angklung* of West Java and to make it a respectable and popular musical instrument again. Tunes similar to Western music were introduced, modern arrangements made, and enthusiasts recruited. Now the *angklung* is a symbol of Sundanese music and occupies a position similar to that of the *gambang* for the Javanese *gamelan*. A complete set of traditional *angklung* consists of 18 pieces. The tunes they produce is the characteristic Sundanese da mi na ti la da, which is different from the Western do re mi fa so la ti do.

The *calung* is another instrument making use of bamboo tubes. Cut diagonally at one end like goose quills, the tubes are closed by a node at the other end. Use of the *calung* is limited to certain districts of the West Javanese province; formerly it was spread over a larger region. In South Banten it consists of 12–14 bamboo tubes (110), whereas in Bogor the *calung* consists of 18 bamboo tubes. According to Kunst (208), the *calung* generally is made up of 12, 14, or 16 tubes, tied together with cords, in a horizontal position like a rope ladder. From the top to the bottom of the instrument, the tubes get lower in pitch and increase in dimensions. When played, the *calung* is hung by its upper end on the wall of a house or a tree, the lower end being tied to the left knee of a sitting player or to the waist of a standing player. It produces sounds when beaten with two *penakols*, namely sickle-shaped wooden sticks of slightly different sizes.

The *gambang* basically is a Javanese musical instrument made of wood and probably can be considered as an Eastern counterpart to the Western piano. The Sundanese in recent years have developed a type of *gambang* that consists of a series of bamboo tubes tied horizontally together by cords on a bamboo platform. This *gambang bambu* is played in the same way as the *calung*. However, the *gambang bambu* is more sophisticated musically because it uses more bamboo tubes and, hence, has more tunes and pentaves. In North and South Celebes a similar bamboo musical instrument is also used but with different tunes.

The *rengkong* is a very rustic musical instrument consisting of only a long piece of bamboo tube. This bamboo is carried on the shoulder of a dancer and on both its ends are suspended — held by string made of split bamboo — bushels of newly harvested rice. The *rengkong* is played usually during a ceremony to appease Dewi Sri when there has been a harvest failure. The rhythmic movement of the dancer's steps causes the suspended rice to swing, and the friction of the string against the bamboo produces the characteristic musical sound. This instrument is found in South Banten and in Sumedang in West Java, but one may also find it played in Pekalongan and Banyumas in Central Java.

The *kohkohl* is an instrument made up of a complete internode that has been slit longitudinally. Sound is produced when the side near the slit is beaten with a soft wooden stick. The size and length of the bamboo tube and the width of the slit determine the sound produced.

The *hatong* is a bamboo pan-pipe, which is usually played in pairs, namely a larger *hatong* with either two or three tubes and a smaller one with from 10 to 14 small tubes. In the district of Caringin in Banten, three different kinds of *hatong* are used during stag hunting: one with a single pipe bears the name *hatong ijen* or *hatong honghong* and is reserved for the leader; the two other kinds, i.e., the double-piped *hatong sekaran* and the three-piped *hatong pangayak*, are blown by the hunters themselves.

Other areas where the *hatong* can still be found are Flores, Timor, the eastern part of the central mountains, and the south coast of New Guinea. According to Kunst (208), the *hatong* is possibly derived from the Chinese name for a funeral trumpet *fa hatong*.

The *suling* is a bamboo transverse flute. The Sundanese recognize the *suling pelog*, which has six stops or holes, the *suling salendro* with four stops, and the *suling degung*, also with four stops but with the second stop from the top invariably much larger than the three others so that the instrument gives the characteristic *degung* scale. In South Banten there exist at least four other different flute forms, namely, the *bangsing* with seven finger holes; the *suling lintang* with two stops; the *calintu*, the mouthpiece of which is formed simply by a notch in the wall of the tube, with five stops; and the *elet*, which is a slit-stopped flute with four, five, or six stops. The bamboo flute is common all over Indonesia.

The *taleot* or *susurilitan* is a small bamboo whistle. Formerly used as a horn by the drivers of horsecarts in certain Sundanese areas, it is now very rarely seen.

The *kolecer* is actually a weathercock, namely propellers attached to a horizontally poised bamboo tube of various sizes. When the wind blows, a sound is produced the tune of which depends on the length and size of the bamboo tubes. By putting out many weathercocks with different sizes of bamboo tubes, one can produce melodious music.

The *celempung* is the name given by the Sundanese to the bamboo stringed instrument. It consists of a complete internode closed at both ends by the nodes, provided with a longitudinal slit and two bamboo strings cleverly split from the slit. This instrument is widely distributed and can be found from Madagascar, Vietnam, Malaya, and all over Indonesia to the Tasadays in the Mindanao of the Philippines. Each area normally has a characteristic number of strings, varying from one to four.

## Species of Bamboos Used in Musical Instruments

In enumerating the various kinds of uses of Indonesian economic plants, Heyne (147) only mentioned that *Schizostachyum blumei* Nees was used in the *suling* in many places. Kunst (208) recorded *bambu tutul* as the kind of bamboo used in the *angklung* in West Java. Field observations have indicated that in recent years *bambu tutul* — or the spotted bamboo, a cultivar of *Bambusa vulgaris* Schrad. — has been used only rarely in the *angklung* and other musical instruments. Thus, despite the widespread use of bamboos in many types of musical instrument, the identities of the species employed have not been established scientifically.

As was reported previously (463), the majority of Sundanese bamboo musical instruments have been exclusively made of *bambu hitam*, a species of bamboo tentatively referred to as *Gigantochloa* aff. *atter* (Hassk.) Kurz ex Munro. The leaf anatomy of this taxon is distinct from that of the true *Gigantochloa atter* (Hassk.) Kurz ex Munro or *bambu temen*, but its floral characters are unknown. Therefore, its taxonomic status has not been satisfactorily decided. The *bambu temen* itself is also used in musical instruments but not as extensively as the much preferred *bambu hitam*.

Occasionally a third species, the *bambu apus* or *Gigantochloa apus* Bl. ex Schultes f., is also employed in low-quality musical instruments, because this bamboo is more readily available than is *bambu hitam*. However, musical authorities and musical-instrument makers agree that this species is unsuitable for musical instruments because its tubes are not straight. There are little swellings near the nodes that apparently cause some disturbance in the sound it produces.

Also, the *bambu hitam* from West Java is considered more suitable and is much preferred to the *bambu hitam* from Central and East Java because the latter tends to have tubes with larger diameters and thicker walls.

## Discussion

In recent years, the number of people becoming interested in bamboo musical instruments has been increasing. There are many musical groups in schools, government institutions, and professional societies that have a set of bamboo instruments at their disposal. Tourists from abroad also like to have real or toy bamboo musical instruments to take home. Nowadays, a complete set of bamboo musical instruments may be obtained for about U.S. $250.

The increasing demands for these musical instruments have not been balanced by the availability of raw materials required for making them. There is a shortage of good and appropriate bamboo for musical instruments largely because of the demand for West Javanese *bambu hitam* from the furniture and handicraft industry. Also, bamboo groves and plantations are disappearing because of the pressure for food crops on the land they occupy.

The price of bamboo suitable for musical instruments is affected by this competition. The cheaper and more readily available *bambu apus* (*Gigantochloa apus*) is being used but is unsuitable for good-quality musical instruments. Therefore appropriate steps should be taken to ensure that suitable *bambu hitam* will always be available for the West Javanese bamboo musical instrument industry.

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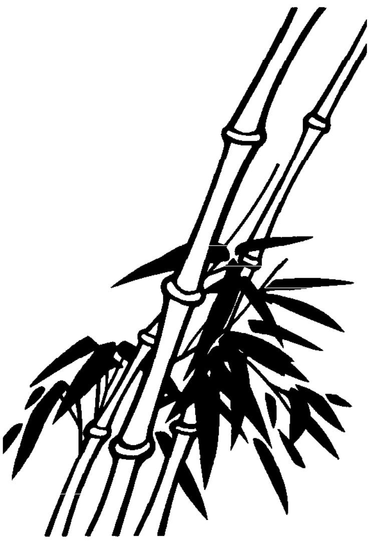


# Discussion Summary

The taxonomy of bamboos in general and identification in particular are subjects that are poorly developed. Although the latter is dependent on the former, there is need for drawing a distinction between the two. The taxonomist must bear in mind the needs and limitations of the forester and prepare field keys based on vegetative characters that can be easily used. The limitations of such keys are generally recognized, and probably one key for the entire Southeast Asian region would be confusing. Therefore, local keys have been suggested. The Forest Research Institute, Dehra Dun, has developed identification charts based on juvenile culm sheaths, juvenile buds, and epidermal peelings of culms and leaves. These keys have proved unsuitable for use by research workers in other countries probably because of the interaction between the genetic composition of the material under study and the environment. One way to solve the problem is to identify and include all the existing varieties. Genetic, cytologic, and anatomical studies are, therefore, important as a basis for taxonomic studies and should be completed as soon as possible. In the meantime, local field keys based on a study of the vegetative characters such as clum form, culm growth, node and internode, culm-wall thickness, culm buds, culm sheaths, nature of branching, etc. will be valuable and should include a list of correct recent names with their synonyms and vernacular names.

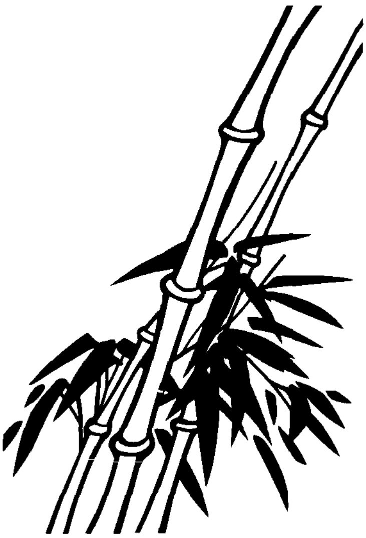
## Propagation

The propagation of bamboos by seed and by vegetative methods has been tried by many research workers, but a satisfactory method is not yet in sight. At present, the best potential is in raising seed stands from all the seedings of the economically important species. For this purpose, exchange of seeds between the countries of the region is important. Publication of a newsletter, which would include news on the seeding of bamboos, is regarded as the best way to encourage this exchange. However, all the countries of the region need to cooperate in the production of the newsletter, feeding information to the publishers as soon as flowering is noticed. On publication of the news, different countries could request seeds from the country where flowering has occurred. Because the seeds of all bamboo species are short-lived, speed in supplying, etc. is very important. In cases where gregarious flowering has occurred, protection from fire and grazing is important as these can become the cause of extermination.

Research on the propagation by vegetative methods will probably have to be made by each country on its own, as exchange of planting material is probably not possible. Such studies need to be carried out up to the point where clumps have been formed after the material has been planted in the field. This method of propagation will be helpful in the multiplication of clumps produced from imported seeds and of the varieties isolated after genetic studies. Further studies using different kinds of experimental material such as undifferentiated cells in the bud need to be taken up. Provided research on packing and safe transportation by air is made, the use of buds in vegetative propagation may make exchange of experimental materials possible.

The utilization of bamboos is so varied that the research needs will be different for each kind of use. However, methods of preservative treatments include felling the bamboos during the dry season, seasoning them with smoke, simply soaking them in water, and applying chemicals to either felled culms or standing ones. Certain structural designs for construction purposes also increase their lifespan. Where bamboos are used as water pipes, regular replacement has been suggested to be safer than the use of chemical treatments unless the latter is well controlled.

The need for a study of the anatomical structure and mechanical strength of bamboo was stressed, especially as these properties relate to the utilization of bamboos.



Appendix

# Collecting Bamboo Specimens for Identification[1]

(1) Never mix material from two distinct plants under the same number, although they probably represent the same bamboo species.

(2) Make complete specimens for permanent preservation. To identify a bamboo with confidence, one should have as complete a representation as possible, by specimens, photographs, and field notes. The specimen should consist of culm sheaths, leafy branches, branch complement, culm nodes, flowering branches (if any), and a young shoot.

(3) How to collect material: each part collected should be numbered according to the collector's field number.

•Culm sheaths. Collect some culm sheaths in good condition and complete with blades and auricles (if present), preferably from nodes above the fifth node of a mature culm. Press flat; if too large for the press, cut or fold. If you cannot spread a sheath without breaking it, let it roll up and do not press it. Tie paper over tips of unpressed sheaths to protect fragile parts. Persistent sheaths may be left attached to a section of culm of appropriate length, dried, and sent in thus. The more complete the series is, the more reliable the identification.
•Leafy branches. Collect twigs or branches with leaf blades of all sizes and ages. Press promptly, before the leaf blades curl.
•Branch complement. Collect at least one typical example of a branch complement from the middle of a mature culm. Cut off branches about 2 inches (5 cm) from their base. Include a segment of culm embracing the selected branch complement. If possible, collect a series of branch complement, from buds to developed branches.
•Culm nodes and internodes. Collect a segment of mature culms embracing nodes four and five aboveground and the internode between. Cut branches to 6 inches (15 cm) long. Segment may be split.
•Rhizome. Obtain at least one complete example of a rhizome to show typical branching habit. Wash and trim roots, take a photograph or a sketch of the rhizome instead of preserving.
•Flowering branches. Collect as much as possible to show range of variation in habit, leafiness, stage of development, etc. Press and dry them promptly.

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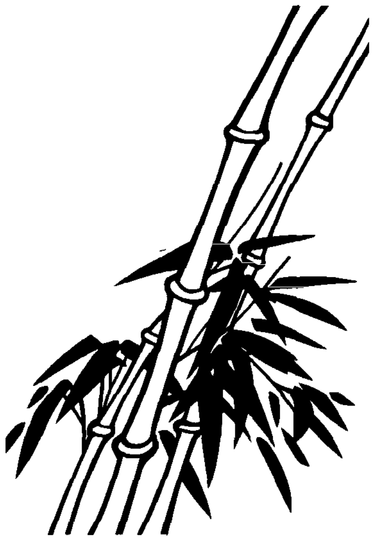
[1]McClure (243) abbreviated by Soejatmi Dransfield.

•Seedlings. Look for seedlings under the clump; if any, press and dry them straight away.

### Field Notes

Make notes of habit of the clump and culm; maximum height and diameter of culm; length of internodes; thickness of culm wall (thin, thick, etc.); location; habitat; local names; local uses; date of collection; name and field number of collector; and, if possible, a picture of the plant.



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