Domestication and Improvement of Bamboos

INBAR Working Paper No: 10

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International Network for Bamboo and Rattan

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INTERNATIONAL NETWORK FOR BAMBOO AND RATTAN

The International Network for Bamboo and Rattan (INBAR) develops, provides and promotes appropriate technologies and other solutions to benefit people and the environment. A world-wide network, it connects governmental and non-governmental organizations and the private sector. INBAR provides leadership, coordination and support for research and development. INBAR's R&D programs cover natural and cultivated raw materials; genetic resources, processing and utilization; economic and other social aspects; and supporting services. INBAR aims to enhance the quality of life of poor and disadvantaged people in developing countries and to make favourable impacts on forests and degraded environments.

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DOMESTICATION AND IMPROVEMENT OF BAMBOOS

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FOREWORD

In the early 1980s, greater attention began to be focused on cooperative networking, especially in Asia, to enhance the sustainable production of bamboo. This was followed by a decade of support by the International Development Research Centre (IDRC), Canada, to national programs concerned with the production and processing of bamboo. By 1993, the International Network for Bamboo and Rattan (INBAR) came into being to promote and facilitate all aspects of research on bamboo and rattan.

At the end of 1991, the United Nations Development Programme (UNDP) established a regional project for technology transfer and training to improve productivity of man-made forests by applying advances in technologies related to tree breeding and propagation. The project, with the acronym FORTIP, is operated through the Food and Agriculture Organization (FAO). Member countries of the FORTIP network have identified the problems associated with productivity as inadequate maintenance of man-made forests, mis-matching the species to sites, and substandard seed and planting materials. Bamboo became one of the three priority species in the region for FORTIP consideration, and a consultancy report was commissioned by FORTIP to explore the domestication and improvement of bamboos.

Since the inception of INBAR in 1993, FORTIP has collaborated closely with it on several initiatives related to bamboo and rattan. An earlier Working Paper on the domestication and improvement of rattan, published by INBAR in 1995, is an example. It was felt by the managers of both networks that the publication of the consultancy report, edited and updated to incorporate key actions in the subject area by INBAR, would be a logical successor to the Working Paper on rattan. It is hoped that this would serve a wider audience, and contribute useful inputs to the understanding of aspects related to the domestication and improvement of bamboo.

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INTRODUCTION

Bamboo is a wonderful gift of nature. Bamboo species are giant, woody, tree-like grasses and have a long history as a versatile and widely-used renewable resource. Especially in Asia, bamboos provide construction material for shelter, tools and implements for agriculture, pulp for paper, and materials for many handicrafts. Besides these versatile uses, man, probably from pre-agricultural times, used bamboo for food. In addition, bamboo conserves soil and regreens eroded slopes. Many cultural traditions in rural areas are intimately connected with bamboo.

Except for homestead cultivation, bamboos have rarely been planted in the forests. Consequently, foresters do not have adequate knowledge of bamboo afforestation or reforestation. Village farmers have knowledge of bamboo cultivation on a limited scale, based mostly on personal experiences and not on systematic scientific studies. The situation calls for immediate attention to more scientific cultivation and mass reproduction to meet increasing demands for planting materials.

Bamboos have long been cultivated in villages, and the rural poor are the principal users of bamboo. According to Tewari (1992) 80 percent of bamboo gets used locally. Previously, bamboo formed a perpetual resource because of its vigorous vegetative growth. But at present, overexploitation associated with growing human population, destruction of tropical forests and new demands on the resources for industrial uses (especially by the pulp and paper industry) have together contributed to severe loss of stock from the once sprawling bamboo forests of Asia. Much of the land of homestead forests in rural Asia are being converted to houses and rice fields to house and feed the growing population. Many countries have been forced to severely restrict – and in some cases even ban outright – the harvesting and exporting of bamboo, resulting in the loss of potentially great economic opportunities. The greatest losses are borne by rural people, as a once abundant and cheap resource is now becoming scarce and expensive.

Among the tropical Asian countries, Bangladesh, India, Sri Lanka and the Philippines have maximum population density, and therefore the problem is more acute in these countries. There is an urgent need for development of a bamboo resource base through a massive program of improved planting stocks. Improvement of bamboo through genetic enhancement has hardly been thought of, although the potential in this field is enormous. The alarming rates of deforestation has also accelerated genetic erosion, especially in areas of indigenous bamboo diversity, in countries such as Indonesia, Malaysia, the Philippines, Thailand and India (mostly in the eastern part). Recently, initiatives have been taken by the International Network for Bamboo and Rattan (INBAR) and the International Plant Genetic Resources Institute (IPGRI) to explore ways and means to promote genetic conservation.

The United Nations Development Programme (UNDP) and the Food and Agriculture Organization (FAO) have jointly developed a project on "Improved Productivity of Man-made Forests Through Application of Technological Advances in Tree Breeding and Propagation (RAS/91/004)" for the Asia-Pacific region. Countries participate in the project, known as FORTIP, as constituents of a regional network. Bamboo has been prioritized as one of the top three species in the region for the project's intervention. This Working Paper, specifically prepared for that project, attempts to provide suitable strategies to improve the productivity of bamboo.

Objectives of an improvement programme

The genetic improvement of agricultural crops has taken place by both unintentional and deliberate selection over many generations. In contrast, selective breeding of commercial forest crops is a development of the 20th century, with most of the activities taking place in its second half (Namkoong et al. 1980). The history of genetic improvement of bamboos is recent and started only about 30 years ago in Japan and China, and more recently in the Indian subcontinent. However, the activities have not yet led to the breeding of bamboo.

A program is needed to:

- Access available knowledge of bamboo breeding and improvement activities in the region.
- Search for socially useful and economically profitable new bamboo genotypes; and
- Develop clonal techniques for mass propagation.

Expected outputs and beneficiaries

Increased bamboo production largely means the improvement of bamboo groves in villages and also partly in government-owned national forests. As no systematic study on the selection of elite bamboo genotypes has so far been undertaken in tropical Asia, enormous potential for improvement exist. The annual productivity of bamboo plantations per hectare could be increased by selecting and multiplying superior genotypes for specific end-use. As bamboo is a fast-growing and quickly harvested crop, the output would be visible within 2-3 years of planting superior genotypes.

The main beneficiary will be the rural poor. However, standard technologies for the production of quality propagules will be needed. Women in particular need to know how to run bamboo nurseries and to earn money by selling planting stocks.

Progress in these areas will directly influence the economy of rural Asia by improving the bamboo resource base. Village people will receive socio-economic benefits through supplying materials at cheap rates, and through generating employment both in harvesting and cottage industries.

Bamboos are extensively used as raw material in the pulp and paper industries and for rayon mills. Many pulp mills in India and Bangladesh are, at present, running below the optimum level of production because of the lack of raw materials. Species, provenances or clones having excellent qualities for pulping would increase the production of the mills and, as a result, the price of paper and paper products could decrease.

China, Thailand and the Philippines have many food industries based on bamboo shoots. In some cases, bamboo shoots have a higher cash value than rice. Thailand alone earns approximately US$30 million through export, meeting about 18 percent of Japan's canned bamboo shoot requirement. New bamboo clones to improve the quality and quantity of edible shoots would enhance the earnings of farmers and canning industries.

Proposed action of FORTIP

Different countries in the FORTIP Network are at different levels of bamboo research. Some have knowledge on propagation and selection of certain species, while others are still in the initial stages of such research. In most countries, bamboo improvement has hardly commenced. Hence, countries of the Network need research backup. Since, every country in the Network will have both short-term and long-term research objectives, clonal propagation of selected bamboo species for large-scale reforestation and rural plantation will be an immediate short-term strategy, while breeding research will be a long-term approach.

FORTIP will be in a position to assist participating countries to enhance national capabilities. In particular, it can help in the availability of germplasm and provide networking services to help standardize techniques between countries. It can also play a major role in technology transfer.

THE RESOURCE BASE

Bamboos are perennial woody members of the Gramineae and belong to the subfamily Bambusoideae. The subfamily is markedly diverse both in reproductive and vegetative characters (Clayton and Renvoize 1986). There are as many as 75 genera and 1 250 species of bamboo distributed in tropical, subtropical and temperate zones of the globe (Sharma 1980). Tropical Asia has been referred to as the centre of bamboo diversity with as many as 45 genera and 750 species (Biswas 1988).

Bamboos, in general, have a tall aerial shoot (culm) with distinct nodes and hollow internodes, and a complex underground rhizome system with a prominent sheathing organ (culm sheath) at each node. The culm is the main part utilized for various purposes. Bamboo diversity often relates to major climatic, soil and all altitudinal differences.

National resources in South and Southeast Asia

A list of the more important bamboo species in a number of South and Southeast Asian countries is given in the Appendix. A summary is presented below.

Bangladesh

More than 30 species are found in Bangladesh out of which seven occur naturally in the semi-evergreen and semi-deciduous forests of Chittagong Hill Tracts, Cox's Bazaar, Sylhet and northern Mymensingh. Among them, muli (*Melocanna baccifera*) is the most common species and forms pure as well as mixed stands. This species constitutes 70-90 percent of the total bamboo forests in the country. Other forest species are: mitinga (*Bambusa tulda*), orah (*Dendrocalamus longispathus*), dalu (*Neohouzeaua dullooa*) and kali (*Oxytenanthera nigrociliata*) occurring sporadically either in association with muli or in isolation forming small patches of pure vegetation. Two other species, lata (*Melocalamus compactiflorus*) and pecha (*Dendrocalamus hamiltonii*), are localized to limited areas of Chittagong and Sylhet forests, respectively. Intensive biotic interference and uncontrolled exploitation have made these two bamboos threatened species. Some taxonomic problems regarding *Bambusa tulda-longispiculata-nutans-teres* complex remain to be solved (Alam 1994).

The thick-walled species are cultivated in villages. Among them bashni, barak (*Bambusa vulgaris*); barua, baluka (*B. balcooa*); talla (*B. longispiculata*); mal, makal (*B. nutans*); and kanta (*B. bambos*) are the most common and used, mainly for construction. Both thick and thin-walled species are major raw materials for pulp and paper industries. All the species found in the forests are thin-walled, and mainly used for thatching and roofing and agricultural purposes.

Bangladesh, being a part of the subtropics, has only clump-forming bamboos. No non-clump forming temperate species are available in the country.

Bhutan

The distribution of bamboos is mainly influenced by topography and altitudinal variations. Sharma (1982) reported that in the lower hills, the main species is *Dendrocalamus hamiltonii*. At about 1 200 m elevation, *Bambusa nutans*, *Dendrocalamus sikkimensis* and *Chimonobambusa intermedia* (now recognized as *Drepanostachyum intermedium*) make their appearance while at 1 200 and 2000 m, the species present are *Cephalostachyum capitatum*, *Pseudostachyum polymorphum* and *Dendrocalamus patellaris*. Between 2 000 and 2 800 m, *Arundinaria racemosa* grows with two other species, *Thamnocalamus aristata* (now recognized as *T. spathiflorus*) and *T. falconeri* (now recognized as *Himalayacalamus falconeri*).

India

India is rich in bamboo resources. Bamboos occur almost ubiquitously in the country, except in Kashmir, and cover about 12.8 percent of the forest area, occupying over 9.57 million ha (Varmah and Bahadur 1980). Areas particularly rich in bamboo are the North-East region, Western Ghats and the Andamans. About 130 species belonging to 24 genera have been reported (Sharma 1987). Of the genera, 20 are indigenous and four are of exotic origin. The principal genera are *Arundinaria*, *Bambusa*, *Cephalostachyum*, *Dendrocalamus*, *Gigantochloa*, *Melocanna* and *Ochlandra* (Sharma 1982). Others include *Neohouzeaua*, *Chimonobambusa*, *Pseudostachyum*, *Thamnocalamus*, *Semiarundinaria*, *Schizostachyum*, *Dinochloa* and *Oxytenanthera*. *Dendrocalamus strictus* is the most common and widely distributed species throughout the country. The Indian paper industry is dependent on this species to a considerable extent for raw material. The other most important species are *Melocanna baccifera*, *Bambusa bambos*, *B. tulda*, *B. vulgaris*, *Ochlandra travancorica* and *O. rheedii*.

Indonesia

Thirty-five species belonging to 11 genera are found throughout Indonesia (Yudodibroto 1987). According to Widjaja (1980), the lack of ample collection of herbarium specimens makes it difficult to present a sound taxonomic judgement on bamboo in Indonesia. There were taxonomic problems in delimiting the *Gigantochloa verticillata-atter-maxima* complex and *Schizostachyum biflorum-blumei-longispiculatum* group[1]. However, a bold estimate for Indonesia would be 65 species. Widjaja (1980) also stated that for almost every genus occurring in Indonesia, a thorough taxonomic revision is needed. A total of 26 000 ha of bamboo forests is found in Banyuwangi, East Java, of which only 7 700 ha is reported economically productive to supply a paper mill. A second bamboo forest complex of over 24 000 ha located in Gowa, South Sulawesi, is also managed by a state-owned paper mill (Yudodibroto 1987).

The common genera are *Arundinaria*, *Bambusa*, *Dendrocalamus*, *Gigantochloa*, *Nastus*, *Phyllostachys*, *Schizostachyum* and *Thyrsostachys*. The most economically important species are *Bambusa bambos*, *B. blumeana*, *B. vulgaris*, *Dendrocalamus asper* and *Gigantochloa atter*. An almost pure forest of *D. asper* exists on the banks of the Amandit river in South Kalimantan. This bamboo grove, approximately 120 ha in area, is said to have been planted by a local tribe of Dayaks about 100 years ago. Bamboos also grow naturally in the forests of Sumatra[2].

Besides the naturally occurring forests, people in Java, Sumatra, Bali and South Sulawesi have cultivated different species. *Bambusa bambos* and *B. blumeana* are the main species planted in relatively dry areas, while *Gigantochloa apus* and *Dendrocalamus asper* are preferred in wetter conditions. Cultivation of bamboo and its use have been intimately linked to rural life. More than 95 percent of the bamboo used in Indonesia comes from farm lands and communities. The bamboo forests in Indonesia are said to represent various stages in retrogression as a result of abiotic interferences.

Malaysia

Bamboos occur gregariously or in isolated patches along streams and river banks, heavily worked out lowlands, forests, hillsides and tops of ridges. Holttum (1958) recognized seven genera and 44 species in the Malayan peninsula. Recently, Abd. Latif and Abd. Razak (1992) reported that there are 70 bamboo species in Malaysia out of which 45 are known to grow naturally in logged-over forest areas. All the species are grouped under 10 genera: *Bambusa*, *Chusquea*, *Dendrocalamus*, *Dinochloa*, *Gigantochloa*, *Phyllostachys*, *Racemobambos*, *Schizostachyum*, *Thyrsostachys* and *Yushania*. About 12 species are commercially utilized, the most extensive being *Gigantochloa scortechinii*.

Nepal

Five genera (*Arundinaria*, *Bambusa*, *Dendrocalamus*, *Drepanostachyum* and *Thamnocalamus*) and more than 30 species have been recorded from Nepal (Das 1990)[3].

Bamboos are abundant between the mid-hills and the Tarai (a flat, fertile river plain), with most of the species being found in the mid-hills. In Nepal, big diameter bamboos are known as "bans",

[1] See Dransfield and Widjaja 1995. *S. biflorum* is now a synonym of *S. iratens,* while *S. longispiculatum* is a synonym for *S. latifolium* or *S. blumei. G. verticillata* is now considered synonymous with *G. atter* or *G. pseudoarundinacea*, and *G. maxima* is now part of *G. pseudoarundinacea*.

[2] More recent data from E.A. Widjaja (1994) updates this.

[3] More recent research by C.M.A. Stapleton (1994a,b) updates this.

smaller ones as "nigalo" and the smallest ones as "malingo". Bamboos are abundant in the eastern, central and western hills and in the Tarai region, but not in the mid-western and far-western regions. Among the different species, *Arundinaria* maling, *Bambusa bambos*, *B. nutans*, *B. balcooa*, *Dendrocalamus hamiltonii*, *D. hookerii* and *D. patellaris* are the most common and useful bamboos.

Pakistan

The arid climate of Pakistan does not favour natural occurrence of bamboos, and the natural distribution of bamboos in the Indian subcontinent becomes scanty towards the west. Further exploration is needed to assess the correct situation for bamboos in Pakistan.

The Philippines

Depending upon the species, bamboos grow in areas from sea level to 2 800 - 3 200 m. Extensive bamboo forests in the Philippines are more of less confined to within 15-25° on either side of the equator (Uchimura 1977). According to Sharma (1987), the Philippines has 55 species of bamboos. Large tracts of bamboos occur in the northern provinces on marginal lands, courses of streams and rivers, village homelots and hillsides. Several climbing species such as *Dinochloa* sp. form dense thickets in the forest in the southern regions. Among different erect species, the more important are: *Bambusa blumeana*, *B. vulgaris*, *Dendrocalamus merrillianus*, *D. latiflorus*, *D. asper*, *Gigantochloa levis*, *Schizostachyum lima* and *S. lumampao*. The major genera of bamboos found in the Philippines are *Arundinaria*, *Bambusa*, *Dendrocalamus*, *Gigantochloa*, *Schizostachyum*, *Thyrso stachys*, *Phyllostachys*, *Cephalostachyum* and *Dinochloa*. Bamboos occur over an area of 7 924 ha which is 0.03 percent of the land area (Tesoro and Espiloy 1990). The bamboos are used in many industries such as housing, construction, handicraft and furniture, fishing, banana orchards, food production and paper.

Sri Lanka

Sri Lanka possesses only 10 bamboo species according to Soderstrom and Ellis (1988). Of the species, *Bambusa bambos* is confined to the dry zones of the country while *Ochlandra stridula* is found extensively in the wet lowlands of the south-western region. Other important species are: *Dendrocalamus giganteus* and *Bambusa vulgaris*. The natural habitat of most species is the forest understorey of swamps and montane grasslands. A new endemic genus *Davidsea* has also been reported from Sri Lanka (de Zoysa, Hettige and Vivekanandan 1990).

Numerous species have been introduced into Sri Lanka of which seven are cultivated. Among them, the yellow variety of *Bambusa vulgaris* is the most widely cultivated, particularly in the rural areas of the wet lowlands and mid-country as well as in the vicinity of waterways in the dry zone. *Dendrocalamus giganteus* is cultivated on a small scale in the wet highlands, whereas *D. asper* and *D. membranaceus* are found in the intermediate highlands. During 1964, *D. strictus* was introduced to Sri Lanka and a few pilot plantations were established in the dry zones (Vivekanandan 1980). Two species of bamboo cultivated for their ornamental value are *B. multiplex* and the recently introduced *Thyrsostachys siamensis*, the former being found in most part of the country, while the latter is currently restricted to urban areas. Other introduced species are not cultivated but are found in the three Botanic Gardens of the country. The native (endemic) *Ochlandra stridula* and the introduced *B. vulgaris* are exclusively used for almost all purposes by the bamboo industry (de Zoysa, Hettige and Vivekanandan 1990).

Thailand

There are 12 genera and 41 species of bamboo recorded in Thailand (Ramyarangsi 1987). Dransfield (1991) reported that about 60 species under 14 genera have been identified. The common species of the country are: *Bambusa blumeana*, *B. nana*, *B. vulgaris*, *Dendrocalamus asper*, *D. membranaceus*, *D. strictus*, *Thyrsostachys oliveri* and *T. siamensis* (Boonchoob 1990). Bamboo grows naturally in the mixed deciduous and tropical evergreen forests or semi-evergreen hill forests, especially in the central highland where the annual rainfall is 1 000 to 2 000 mm. However, the natural distribution of bamboo in these forests has been greatly altered by human intervention. Like in other countries, bamboos are mainly used in construction works, housing, cottage industries, food, fishing, agricultural activities and industries.

Morphology, phenology and growth habit

A bamboo plant has many jointed, cylindrical, hollow stems called the culms. The stems are connected to a rhizome network that spreads out horizontally beneath the soil. The rhizome system constitutes the structural foundation of the plant, and the culm is completely dependent upon the nutrition provided by the rhizome and the older culms (Liese 1985).

The individual rhizome is a segmented axis of the total underground rhizome consisting typically of two parts: the rhizome proper and the rhizome neck. The neck is basal to the rhizome proper, generally shorter in length (clump-forming bamboos) and obconical in shape, but in some cases (*Melocanna* sp.) it may be greatly elongated. The neck connects the new rhizome to the mother rhizome. Two major rhizome types are found in bamboos: pachymorph and leptomorph (McClure 1966). All clump-forming bamboo species have pachymorph rhizomes, whereas all the non-clump forming species have leptomorph rhizomes (McClure 1966, Ueda 1960). Pachymorph rhizomes are short, thick, subfusiform and usually more or less curved in shape, with a thickness that is usually greater than that of the culm into which they are always transformed apically. The rhizome internodes are broader than long, asymmetrical and solid (Soderstrom and Calderon 1979b). Lateral buds of a pachymorph rhizome produce new rhizomes, but a culm originates only from the distal end of a rhizome axis. Leptomorph rhizomes are long and slender, cylindrical or subcylindrical, with a diameter usually less than that of the culms originating from them. The internodes are longer than broad, symmetrical or nearly so and typically hollow (Soderstrom and Calderon 1979b). Shigematsu (1960) mentioned that the pachymorph rhizome is typically a summer sprouting type, for which mainly soil moisture and temperature are important, and the leptomorph is characteristically spring sprouting, for which temperature is the limiting factor. Between the single-stemmed (leptomorph) and the densely clumped (pachymorph) forms, there are intermediate types (woody-pachymorph-diffuse) forming somewhat open clumps (Watanabe 1986).

The shoot starts to emerge from the soil mostly at the beginning of the rainy season. Shoot elongation continues both during the day and the night. The genus *Phyllostachys* in Japan grows more during the day (Ueda 1960), whereas in the tropical regions, bamboos grow more during the night (Osmaston 1918). The daily (24-hour) extension growth amounts to about 10-30 cm, but reaches 58 cm for *Dendrocalamus giganteus* (Osmaston 1918), and up to 121 cm per day for *Phyllostachys reticulata* (Ueda 1960). In respect of major bamboo species of Bangladesh, Banik (1993a) reported that maximum elongation per day was 44 cm in *Melocanna baccifera*, 66 cm in *Bambusa vulgaris* and 77 cm in *B. balcooa*. Being a monocotyledonous plant, bamboo does not thicken from secondary growth. An emerging culm reaches full height within 2-4 months (McClure 1966, Ueda 1960). Banik (1991) observed that in Bangladesh a bamboo clump starts producing culms generally either from May or June and may continue for up to 6-7 months. Each species of bamboo has a definite periodicity for culm emergence. The total culm elongation periods were observed to be 75-85 days for *B. balcooa* and *B. vulgaris*, and 55-60 days for *M. baccifera*. The height of the culm results mainly by elongation of internodes. Internodal elongation begins at the basal portion of the culm and then gradually proceed to the top because of the intercalary meristem present at the node.

All emerging culms do not develop into fully grown culms. The natural mortality of emerging culms tends to be high (28-69%) in thick-walled and tall species and low (9-37%) in thin-walled and shorter species (Banik 1983). Mortality of emerging culms is higher (50-60%) in September and October when average rainfall is low (Banik 1983). Eco-physiological conditions – such as clump congestion, soil moisture, food storage and genetic make-up of each species and clump – seem to influence the rate of mortality of emerging culms.

The clump height depends on the total length of the culm and it varies from 2-37 m, depending on the species. The length of the culm internode increases gradually from the base towards the middle portion and decreases upwards. The growing culm is without branches, and branching begins either after the culm has ceased growth or in the following growth season. Bud dormancy and the breaking of it vary with the nodal position (Banik 1980). Takenouchi (1931) was the first to call attention to the order of breaking of branch buds on the young culm. Banik (1980) reported the pattern of bud break on the culm node of different bamboo species of Bangladesh. In *Neohouzeaua dullooa* and *Melocanna baccifera*, the breaking of bud dormancy on the node of a culm was found to be in basipetal order, gradually moving towards the base and being completed in 3-4 years. Although, essentially, the same pattern was observed in *Bambusa vulgaris*, 5-10 buds around the middle of the culm remained dormant for up to 3 years. After that, all opened except those in the 2-3 base nodes. In *B. tulda*, all the buds opened at nearly the same time with the exception of a few at the mid-culm or lower. Most of the remaining buds started opening at about age 1-2 years. Generally, in bamboos of Bangladesh, new leaves and branches start developing during March-April from the culm buds and branch buds after each defoliation. Bamboos are, however, not purely evergreen plants. Most bamboos in Japan change leaves in the period from spring to early summer, whereas clump-forming types in the tropical regions such as India shed their leaves in winter and renew them in a short time (Ueda 1960). According to Banik (1980), buds are more active in March-April than at other times, and this could be the best season for collecting buds or branches as vegetative propagules. The buds on the culm nodes are protected by culm sheaths on alternating sides. The size, shape, form and different parts of culm sheaths are diagnostic for each species (Chatterjee and Raizada 1963). Culm sheaths may be persistent or fall off from culm internodes, depending on the species.

Culms of most bamboos are hollow and erect; but some have solid, and either erect, scandent or climbing culms (Liese 1985). *Dendrocalamus strictus* growing in drier part of western India, generally, has solid culms (Kadambi 1949). The thickness of the culm wall varies 1-3 cm, depending on the species. Bamboos can be grouped into thin and thick-walled species. Branches in some species may be thorny while most are thornless.

The age of a culm is difficult to determine. Generally, culms which are 3-5 years old are considered "mature". After completion of elongation, carbohydrates from the assimilating leaves are still transformed into cell wall material and deposited on existing walls of the culm (Liese 1985). The evidence from chemical and technological tests regarding the beginning of "maturity" is still contradictory. However, presence or absence of culm sheaths and nodal rootings, bud break and branching pattern, and colour are diagnostic morphological characters for determining the age of culms (Banik 1993b).

The diameter of successively emerged culms increases with the age of the culms (Banik 1988). In the first few years, the culms are small and reach their maximum diameter after the fourth or fifth year. The mean diameter varies with the species but is also influenced by environmental conditions. The knowledge on the growth behaviour of Indian bamboos is scanty. An elaborate management system has been developed (Seth 1954) only for *Dendrocalamus strictus* and a few other clump-forming bamboo species of the sub-continent based on their growth habits studied earlier by Deogun (1937), Kadambi (1949), Sen Gupta (1952), Krishnaswamy (1956) and others. Recently, Banik (1988) studied the growth habit of culm in the clumps of five different species in Bangladesh. He reported that culm production gradually increased up to the fifth year of planting in the case of *Bambusa* species. After that period, culm production gradually decreased, although the increase in diameter and height was more or less similar to those of previous years. Similarly, clump girth expansion was rapid up to the fifth or sixth year of plantation. Seth (1954) developed a felling system for *D. strictus* and a few others involving time of felling, height of culm cutting, number of culms to be cut, and cleaning and improvement thinning. Cleaning operations relieve congestion in clumps and dense stands, promote regeneration, and facilitate harvesting. According to Huberman (1959), due consideration must be given to even spacing to relieve culm congestion.

General distribution

Bamboos occur naturally in all continents except Europe in the tropics, subtropics and mild temperate regions of the world, but distribution is uneven. Some bamboos were recorded from latitude as far north as 46° and as far south as 47°, and occurring at elevations as high as 4 000 m (Soderstrom and Calderon 1979b). Marden (1980) has given a broad outline of distribution (Figure 1). Great majority of bamboos are found in the southern and south-eastern borders of Asia, from India to Japan. Three endemic species have been described from Australia. In the Western Hemisphere, the known natural distribution of bamboos extends from 39°25'N in eastern United States to 45°23'30"S in Chile and to 47°S in Argentina. The distribution of bamboo is rich and gregarious in the areas between the Tropic of Cancer and the Tropic of Capricorn, specially for clump-forming bamboos (Uchimura 1987).

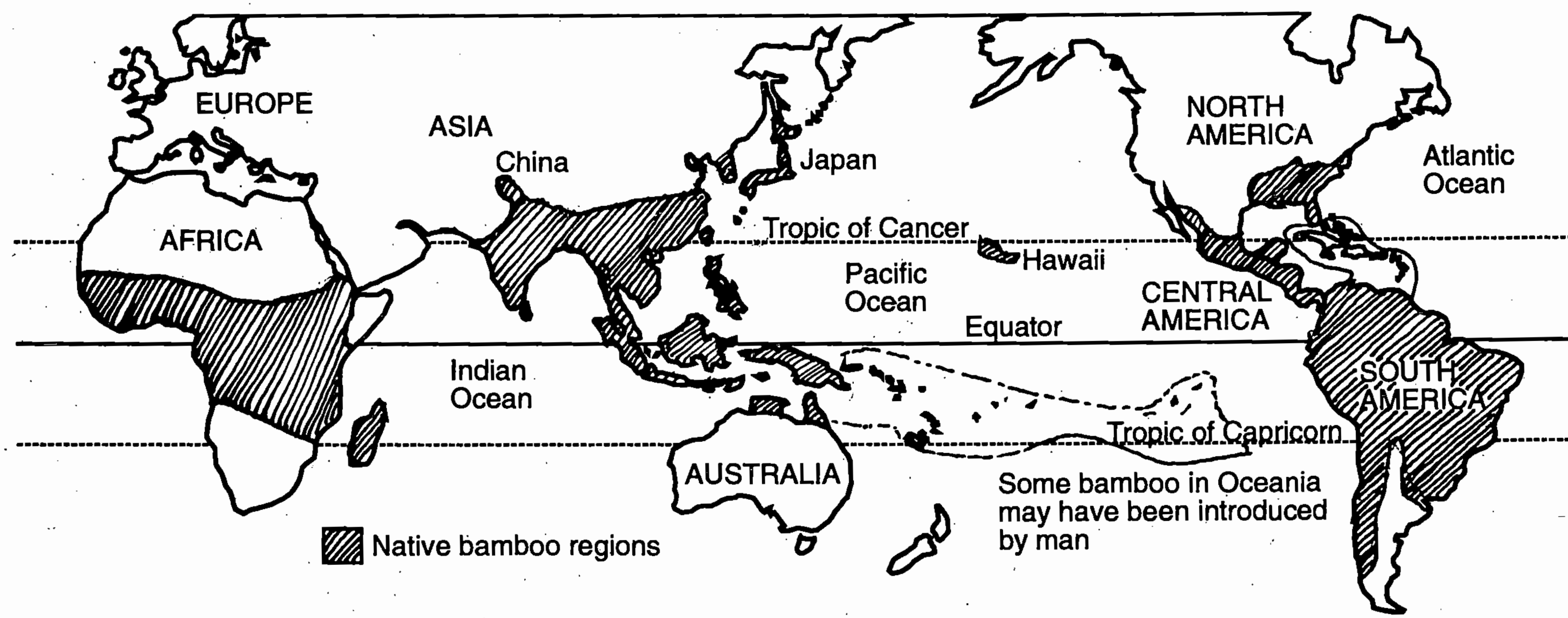

Fig. 1: A broad outline of the native bamboo regions in different continents of the world (Morden 1980)

Environmental determinants

The following environmental conditions are the major requirements for optimum growth of bamboo species (Uchimura 1987).

Temperature

The majority of clump-forming bamboos grows at temperature ranges from 7° (sometimes 2-3°C) 40°C. In general, high temperature accelerates the growth of bamboo while low temperature inhibits it. The clump-forming types are generally present in the humid tropics mainly in places where the average temperature is higher than 20°C, and where the altitude is less than 100 m above the sea level.

Altitude

Non-clump forming types of bamboos grow naturally in areas higher than 1 000 m in the tropical region. However, these groups are mostly confined to the temperate zones of the world. Non-clump forming types such as *Phyllostachys*, *Semiarundinaria*, *Sinobambusa* and *Tetraganocalamus* are the common genera which grow in the temperate regions and sometimes at high altitudes of subtropical areas.

Rainfall and cyclones

Numata (1987) stated that high temperature and humidity requirements are common characteristics of plants originating in the monsoon areas of South-East Asia. As the water requirement of bamboo is high, the amount of rainfall is also a limiting factor to distribution. Rainfall is an important factor and 1 000 mm seems to mark the minimum annual precipitation required. Gamble (1896) reported that distribution of bamboos in India was related to the rainfall, the most common range being 1 270 to 4 050 mm. The upper limit is not known, but the species are found to grow in zones with over 6 350 mm rainfall (Huberman 1959). The most common range is 1 200 to 4 000 mm per year.

The effect of cyclones on the growth and development of bamboos is not known. However, Shigematsu (1960) did some experiments on *Bambusa* and *Phyllostachys* and established the need for shelter from strong wind. Sites with more than 100 stormy days (with a wind velocity of 10 m/s or above) cannot produce bamboos of good quality (Numata 1987).

Soils

Most bamboos are found in well-drained, sandy to clayey loam soils, derived from river alluvium of flat or gentle slope areas. *Bambusa polymorpha* and *B. bambos* grow on well-drained and fertile soil under forest trees while *B. tulda* and *Oxytenanthera albociliata* are best suited for sandy soil. Furthermore, *Dendrocalamus strictus* in India, *B. blumeana* in the Philippines and *B. multiplex* in northern Malaysia display strong drought resistance (Uchimura 1987). Soil pH of about 5.0-6.5 is the most suitable for bamboo, but some species may grow even at pH 3.5. Saline soil is not suitable for bamboo growth. A wide range of textural variation and soil depth, however, do not interfere in the normal growth of bamboo, provided the drainage, rainfall and temperature conditions are favourable (Qureshi et al. 1969). Although bamboo prefers well-drained and aerated soils, it can also grow in swampy or wet areas. According to Uchimura (1980), soils high in nitrogen and oxides of phosphorus, potassium, calcium and silicon best promote the growth of bamboo culms. He and Ye (1987) investigated the properties of soil below *Phyllostachys pubescence* in Anji country and Zhejiang, and observed that soil nitrogen content was the most important factor affecting growth. Treatment with a nitrogenous fertilizer has been recommended for stands of low productivity.

Pests and diseases

Very little attention has been paid to pests and diseases in bamboos. A number of reports from India, and a few from Bangladesh, Thailand, Indonesia and Malaysia have been published on insect attacks and fungal diseases in bamboos of the region (Mathur 1943, Boa 1987, Mohanan 1990, Singh 1990, Choldumrongkul 1994). Recently, Tewari (1992) has reviewed the details of insect pests, diseases and decay of bamboos of the Indian subcontinent and other countries of the Indo-China and Malayan region. Although a large number of insects (about 200 species) have been reported from bamboos in the Indian subcontinent, very little information is available on the insect pests of standing bamboos, and much less in known regarding their impact on the growth (Singh 1990).

Bamboo is more susceptible to biodeteriorating agents as compared to timber. These agents include fungi, termites, and especially insect borers such as powder post beetles. Bamboos stored for use in paper mills are liable to attack by insect pests and fungi. It has been estimated that a loss of about 22 percent in wood substance occurs during storage.

A preliminary provisional list of fungal diseases of bamboo has been published by Boa (1987). Bamboos suffer from attack of foliage rusts, leaf spots, decays and discolourations.

Present and potential production and utilization

Liese (1992) pointed out that 2.5 billion people depend on or use bamboo to a value of US$7 billion per year. The estimate is conservative. Most of the people of Asia, and many in Africa and South America, are dependent on bamboo for housing.

The world's annual production of bamboo has been estimated at more than 20 million tonnes (Table 1). Since production is influenced by temperature, precipitation and soil, annual output of bamboo sometimes fluctuates within wide margins. Also large-scale death of bamboo clumps from gregarious flowering affects production. In general, the yield of bamboo varies depending upon the intensity of stocking and biotic interference from 0.2 to 4.0 t/ha, and in most cases is not very encouraging.

Recently, Banik (1992) estimated the present and future demand and supply of bamboos in Bangladesh. Bangladesh has significant bamboo resources located in both forests and villages. The current demand estimate is 706 million bamboo culms, while the need by the year 2013 will be about 900 million culms. Demand projections include rural, urban and industrial requirements. The shortfall will increase by the year 2000 because of the large-scale death of muli bamboo (*Melocanna baccifera*) a major forest bamboo species, as a result of gregarious flowering. At present, village forests supply 80 percent of the total national supply – about 528 million pieces compared with 128 million pieces from national forests. However, the forest bamboo growing area is decreasing at an average of two percent annually owing to overexploitation, poor maintenance and low yield.

Table 1: Consumption (%) of bamboos in the selected countries of Asia by end-use

Country	Construction		Rural Uses	Packaging	Pulp Manufacture	Other Uses
	Housing	Others				
Bangladesh	50	10	20	5	10	5
India	16	16	30	7	17	14
Japan	24	7	18	7	4	40
Myanmar	30	30	32	5	-	1
The Philippines	80	-	15	2	-	3
Thailand	33	20	6	-	8	33

(Source: Sharma 1980)

The total annual bamboo demand of India has been estimated to be around 5 million tonnes, of which about 3.5 million tonnes are required by the pulp and paper industry alone (Sharma 1987). Future projections show a shortfall of 4.32 million tonnes of raw material in this industry by the turn of the 21st century (Adkoli 1990).

Bamboo is used in Nepal in 180 different ways, the most visible ones being basketry, housing and scaffoldings (Poudyal 1994).

The annual production of bamboos in Thailand has been estimated to be about 600 million culms, worth more than US$7 million (Boonchoob 1990). Thailand exports bamboos, and bamboo products such as bamboo board, fishing rods and edible shoots to various countries, earning about US$ 0.5 million annually since 1973.

Bamboo stocks in the Philippines have dwindled considerably because of high demand (Lantican et al. 1987). There is a need to increase planting and productivity of bamboo to meet demands.

In Indonesia, a very rough estimate of total annual bamboo production from Java, Bali, Sumatra and South Sulawesi is between 29 to 146 million culms. Evidence shows increasing demand by industry in addition to the need to sustain local needs.

It is clear that if the bamboo reserves are not scientifically maintained and cultivation is not enriched, the demand for the resources will exceed supply in the near future in all producing countries. This will erode the genetic material. Rao (1992) noted the lack of information on widespread cutting and what percentage is being replanted.

The need for bamboo improvement

Very little work on bamboo improvement has been going on in the countries of the region (Table 2). Maximum efforts have been made on propagation. Recently different Institutes and Universities have achieved noteworthy success in the field of tissue culture for clonal propagation of bamboos.

Table 2: Matrix presentation of activities on genetical improvement of bamboos in the different countries of Indo-Malesian region

Research activities	BANG	BHUT	INDI	INDO	MALA	NEPA	PAKI	PHIL	SRIL	THAI
Inventory	++	+	++	++	++	+	+	++	++	++
Species identification	++	+	++	++	+	+	+	++	+	++
Species trials	+	0	++	+	+	+	0	++	++	++
Provenance trials	++	0	++	0	0	0	0	0	0	+
Seedling selection	++	0	++	0	0	0	0	0	0	0
Species collection	+++	0	+++	++	++	+	0	++	++	+++
Reproductive biology	++	0	++	0	0	0	0	0	0	++
Seed propagation	++	0	++	0	0	+	0	+	+	++
Veg. propagation	+++	+	+++	++	+	++	+	+++	++	++
Tissue culture	++	0	+++	0	+	++	0	++	+	+++
Cytogenetics	0	0	++	0	0	0	0	0	0	0
Polyploidy	0	0	+	0	0	0	0	0	0	0
Induced mutation	+	0	+	0	0	0	0	0	0	0
Hybridization	0	0	+	0	0	0	0	0	0	0

Note: + = Sporadic study ++ = Systematic study +++ = Intensive study 0 = Not studied or unknown.

Source: Varmah and Bahadur 1980, Banik 1987, Gaur 1987, Lantican et al. 1987, Saleh and Wong 1987, Vivekanandan 1987, Yudodibroto 1987, Boonchoob 1990, Das 1990.

In 1991, a review of research commissioned by donors under the leadership of IDRC, Canada, noted the following needs for strategic research (Williams et al. 1991).

- Selection of superior strains and improved cultivation methods to enhance economic production of bamboo are required. The most serious human issue concerning bamboo is the shortage of raw materials. Overexploitation by the pulp and paper industry of local resources is a leading cause of shortage.

- Genetic enhancement of bamboo is a major imperative and priorities must be developed quickly with breeding aims set by local programs. Breeding for wider adaptability should become a medium-term aim, and here there are major opportunities for application of biotechnological methods.

- Some priorities have already been identified for breeding. For bamboo, these have related largely to industrial uses, e.g. enhancement of fibre and paper making quality of *Phyllostachys pubescens;* development of giant bamboo strains capable of withstanding drought or growing in low rainfall regions; and development of a bamboo that can be annually or biennially harvested. The importance of involving rural people, as opposed to plantation interests, must be stressed because of the impact on employment opportunities.

- Through much of the bamboo region of Asia, useful bamboos are cultivated, and there must be considerable knowledge concerning the sustainable utilization of planted bamboo that could be applied to harvesting from the wild.

- Although examples of successful attempts in producing bamboo plantations are available, they are largely isolated and technology standardization has not been achieved as is the case of, for example, fast growing tree species. It is therefore necessary to evolve appropriate technology for raising plantations of selected bamboo and rattan species and particularly in:

  (i) Degraded areas
  (ii) Logged over forest
  (iii) Marginal farmland in agroforestry initiatives.

- Development of plantation techniques rely on development of basis agronomic studies, but additionally require well developed planting materials. Specific issues to be addressed are:

  (i) Establishment of seed multiplication and storage centres.
  (ii) Propagation through various vegetative techniques.
  (iii) Tissue culture for mass propagation
  (iv) Specific techniques applicable to key agro-ecologies.
  (v) Integration with agricultural/horticultural crops.
  (vi) Examination of the question of monoclonal versus polyclonal plantations.

- Techniques are becoming available for the mass propagation of bamboo and rattan using *in vitro* techniques. These have not been applied on a large scale, and sometimes are not repeatable. Much research remains to be done in this area.

In the period from about 1986, governments in many Asian countries have prioritized bamboo as a most important multipurpose crop, and have been supporting different R&D activities (Table 2). Besides this, about 30-50 years back, China, Japan and India have started research on many important aspects, including improvement of bamboos, and contributed much to the knowledge of bamboo enhancement.

Activities related to bamboo improvement

Reproductive biology

Flowering cycle and behaviour

The flowering of bamboo is not yet well understood. Attempts in the past were concentrated on determining seeding cycles rather than flowering cycles so that seeding cycle could be predicted. Most of the bamboo species die after gregarious flowering. The flowering and the death of bamboo forests result in marked shortage of raw materials. However, no information on dependable symptoms of flowering are known by which one could forecast the flowering at least one year ahead (Banik 1986). Because of the long intervals between flowering, it is very difficult to conduct any breeding.

On the basis of flowering behaviour, Brandis (1906) described three major groups of bamboos as follows:

1. Those that flower annually, or nearly so;
2. Those that flower gregariously and periodically; and
3. Those that flower irregularly.

However, a species may exhibit flowering behaviour characteristic of more than one of these groups. *Dendrocalamus hamiltonii*, for example, flowers sporadically almost every year, but may also flower gregariously at 30 years intervals. A range of 25 to 35 years was regarded by Kurz (1876) as the general age at which the common kinds of Malayan and Indian bamboos belonging to *Bambusa* and *Dendrocalamus* come into flower. Intervals of flowering period in non-clump forming bamboos (temperate types) were in the range of 60-120 years (Ueda 1960). Janzen (1976), analysing past reports on flowering cycles in different species, concluded that the flowering cycle ranges from 3 to 120 years; and most are between 15 and 60 years. Such gregarious flowering of single species of bamboo in particular areas, at more or less regular intervals of many years, does not normally occur in the equitable climate of Malayan region (Holttum 1958). The native species of Malaysia can go on growing indefinitely, flowering sporadically from time to time or, in some cases, flowering a little almost continuously. After an unusually heavy flowering, a clump may die back for a time but gregarious flowering in unknown. Similarly, Anan (1990) also reported that many bamboo species of Thailand flower frequently and almost every year.

Almost all past reports on bamboo flowering are based on speculation and estimation (Hasan 1973, Janzen 1976). The exact seeding cycle (from seed to seed) is known only in very few species. It has been possible, however, to determine the exact period of flowering cycles of some Indian species for those introduced into regions outside their natural habitat. Estimated flowering cycle and nature of some bamboo species of Indo-Malesian zone is given by Banik (1993b). The seeding cycle seems to be fixed in nearly all species. Recent analysis of flowering and sterile specimens in major herbaria indicated that Sino-Himalayan bamboos generally flower and die after vegetative periods which are integral multiples (x 1-8) of 10-12.5 years or, in the west, 14-16.5 years (Campbell 1987).

Flowering and death of bamboo clumps

On the basis of senescence behaviour in relation to flowering, Ghinkul (1936) classified bamboo plants into three groups as follows:

1. Plants dying regularly after the first and only fruition;
2. Plants dying in part and renewing the dead parts after fruiting; and
3. Mostly small plants whose life-span is undetermined, flowering and bearing fruit repeatedly at short intervals without dying.

It has been observed that a flowering bamboo clump does not die until all the vegetative buds (leaf buds) are transformed into flower buds (Ueda 1960). Soderstrom and Calderon (1976) hypothesized that all of the members of a bamboo species 'know' when flowering time is at hand. This 'knowledge' seems to be in a genetically imprinted biological clock.

Inflorescence character and flowering structure

It has been observed in different bamboo species that the inflorescence is an indeterminate compound panicle, usually large, with spicate branches on which spikelet-like branches develop. McClure (1966) termed these spikelet-like branches pseudospikelets. Each of the pseudospikelets consist of a number of florets. Banik (1986, 1991) studied flowering biology of some species of Bangladesh. According to him, bamboo usually produces distinct floral shoots (excepting *Bambusa multiplex (glaucescens)*, *B. longispiculata*) in the month of September to January. The complete development of pseudospikelets and their blooming on the floral shoots take place during 3-7 weeks period and varies with the species. So initiation, development and blooming of flowers take place during the dry season of the year. Troup (1921) and Kadambi (1949) reported that drought influences flowering in bamboos. *B. bambos* var. *spinosa* produces leafless floral shoots directly both on the nodes of culms and branches. In the case of *B. vulgaris*, floral shoots mainly develop from the branch nodes and are not completely leafless. Very long (50-120 cm) leafless floral shoots are generally observed only on broken and cut culms. These longer floral shoots have more pseudospikelets (11-19) in each node. Thus, it appears that injury enhances flowering intensity in bamboos. *Dendrocalamus longispathus* also produces long leafless floral shoots, which are unlike vegetative shoots and are slightly zigzag or wavy in nature. The branches are glaucous green and the floral buds are arranged alternately on each node and covered with a branch sheath. Pseudospikelets develop in cluster (somewhat round) at each node on the floral shoot. The inflorescences in *B. glaucescens* and *B. longispiculata* are short panicles, and do not develop on any specialized branches (floral shoots) as observed in other species (Banik 1986). The pseudospikelets are loosely arranged forming clusters and develop directly on the primary and secondary leafy branches. At the initial stage in *B. tulda*, no floral shoots are observed and the inflorescences are also small and born directly on the leafy branches. The pseudospikelets are comparatively bigger in size and also loosely arranged. However, after about 1-2 months of first blooming, vegetative branches rapidly shed leaves and buds on the branches develop elongated floral shoots instead of leaves.

The flower structure of bamboo is composed of lemma, palea, stamen, pistil and lodicule. When flowering, floral glumes open, stamens stretch out and the stigma separates in three directions. The flowers are open for about 2-3 hours, and then close. When the weather is dry, they will close more quickly. In some species, e.g. *Dendrocalamus latiflorus*, the pistils first extend out of glumes, followed by stamens a few days later. In case the glumes do not open, it is difficult to know when bamboo flowers are suitable for pollination. Therefore, anthesis should be determined before pollination. Pollen scatters after the flowers have opened for about one hour, or earlier if the temperature is high and the humidity is low (Guang-chu and Fu-qiu 1987).

The initiation of inflorescence in *Melocanna baccifera* is distinctly different. The thin leafy branches produce leafless elongated floral shoots always at the apex. The nodes along with buds on the floral shoots are covered with small sheaths. The floral buds produce pseudospikelets on one side of the branches. Soon after flowering, the leaves below the floral shoots rapidly turn yellow and wither, and after that the buds on the nodes of the branches produce short panicles. In this species, both flowering and fruiting are continuous. No such information is available on Malayan bamboos.

Clump behaviour to flowering intensity and duration

All the culms of different age groups in each of the clumps of *Bambusa bambos* var. *spinosa* and *Melocanna baccifera* produce flowers simultaneously. In *B. bambos* var. *spinosa*, flowering starts in the first week of February and is completed in early April (within 3 months). Then all the clumps die. The clumps of *M. baccifera* take almost one year to complete the flowering and then die. Thus the clumps in these two species are complete-flowering in nature (Banik 1991).

In *B. glaucescens*, all the 1, 2 and 3-year old culms in the clump flower partially (produce both leaves and flowers), whereas 4-year old culms flower completely. The species takes 2 years to complete flowering (Banik 1986). Therefore, *B. glaucescens* is part-flowering in nature. The clumps of *B. longispiculata* and *B. nutans* produce only a few partially flowering (0.2-8.0%) branches. No flowering was observed in the younger culms which emerged in the current year of flowering. Flowering branches are mainly confined to lower mid-positions of the culms. Among five clumps of *B. longispiculata*, four completed flowering within 2-3 years and then died, while the remaining ones have been flowering for the last 12 years and have not yet died. Thus, the clumps observed in this species show both a part-flowering and complete-flowering nature.

Irrespective of age, all the culms of flowering clumps of *B. tulda* produce both partially and fully flowered branches. Banik (1991) reported that out of 10 clumps studied nine were complete-flowering in nature, whereas one clump showed part-flowering behaviour. Among seven flowering clumps of *D. longispathus*, four clumps were complete-flowering in nature. The remaining three clumps were part-flowering, where flowering period was 2 years (1978-79) for two clumps and three years (1977-1979) for one clump. Out of seven clumps of *B. vulgaris*, five flowered completely and died within 18 months. In the first year, these clumps flowered profusely up to September with a pause from October to January and then completed flowering within next July through irregular flowering. The remaining two clumps were found to be part-flowering in nature. Out of these two part-flowering clumps, one died after 3 years and the remaining one stopped flowering and revived. It was learned from villagers that all the five complete-flowering and part-flowering clumps had been planted from two completely different stocks through offsets. Thus, it is likely that this species might have two genetical or physiological strains, one part-flowering and other complete-flowering (Banik 1979).

Flowering and culm emergence

Troup (1921) reported that checking of new culm production from a bamboo clump could be a reliable sign to predict flowering in the following years. Contrary to his statement, Banik (1986) observed that this is not true for all bamboo species. Complete-flowering clumps of *Bambusa bambos* and *Melocanna baccifera* do not produce any culms in the current year of flowering, whereas those of *B. tulda*, *B. vulgaris* and *Dendrocalamus longispathus* produce culms though few in number. All the part-flowering clumps of different species, excepting *B. glaucescens*, produce culms in the current year of flowering. However, all these species produce culms in the preceding year of flowering as well (Table 3).

Blooming nature and seed yield

Banik (1986) observed that blooming in a bamboo clump (both part or complete-flowering) is not continuous; rather it occurs in three distinct successive flushes (flush period) with two non-blooming periods (rest period) in between. In case of part-flowering clumps, where flowering continues for 2-3 years, the flush and rest periods are distinctly identifiable generally in the first year of flowering. Nicholson (1945) also observed that flowering in *Bambusa bambos* was not continuous; rather the species flowered successively three times in the flowering year.

Table 3: Average culm production per clump during current and preceding years of flowering

Species	Clump flowered		Culms produced per clump			
	Nature	Number	Current year	Preceding year		
				1	2	3
Bambusa bambos var. *spinosa*	complete	3	0	2.0	2.3	2.0
B. glaucescens (*multiplex*)	part	1	0	8.0	6.0	4.0
B. longispiculata	part	5	4.2	4.0	3.2	2.6
B. tulda	part	1	2.0	3.0	3.0	2.0
B. vulgaris	complete	5	1.6	6.8	6.0	-
Dendrocalamus longispathus	1 part	3	1.0	3.7	12.3	17.3
	2 complete	4	0.5	6.0	5.8	3.5
Melocanna baccifera	complete	5	0	8.0	17.0	12.0

Source: Banik 1991

It is observed that the total duration of all three flush periods in *B. glaucescens*, *B. vulgaris* and *Dendrocalamus longispathus* are (50+20+9) = 79 days, (75+68+44) = 187 days, and (55+26+9) = 90 days, respectively, whereas in case of *B. bambos* it is only (12+15+13) = 40 days. Such data are important since it appears that for obtaining the maximum amount of viable seeds from *B. glaucescens* and *D. longispathus* collection should be done in the first two flushes.

Pollination

Opening of flowers and pollen discharge in species reported above mostly occurred in the morning from 6 to 9 AM (Banik 1986). On touching or with gentle air movement the anthers of all the species, especially *Bambusa tulda* and *Dendrocalamus longispathus*, discharge pollen grains in the form of a pollen cloud.

It has been observed through a preliminary acetocarmine test that between 70 and 92 percent pollen of *B. vulgaris* did not take any stain, thus indicating high sterility. This might be one reason why the species did not produce any seed. During anthesis, honey bees and few ants were found to visit the bamboo flowers. Most species produce pollen of high viability. The germination capacity is lost completely in water, or during exposure to sunshine or dry conditions for about half an hour (Zhang and Chen 1991). When flowering is asynchronous, cold storage (at 4°C) can be adopted to preserve pollen viability.

Seed production in bamboo is much lower in the case of self-pollination compared to cross-pollination. Bamboos are generally regarded as cross-pollinators.

Cytogenetics

The cytology of most species of bamboo is not well known. A few cytogenetical studies have been made in India, China and Japan. It has been reported that many bamboos studied, so far, are tetraploids; *Dendrocalamus* and Asiatic species of *Bambusa* are hexaploid (Varmah and Bahadur 1980). The somatic chromosome number of some bamboo species is given in Tewari (1992) and the number varies from 48 to 96. The haploid chromosome number seems to be 9, 8, 6 or 12, but there is some controversy (Guang-chu 1987, Tewari 1992). It is generally agreed that the common somatic chromosome number of tropical and temperate bamboos are 72 and 48, respectively. In addition to these, many bamboo species of the southern subtropical zone of China have $2n=64$.

Diploids have so far been found only among the herbaceous bambusoid grasses. Diploid bamboo species are not known yet (Ueda 1960). Scientists expect to find diploid bamboo somewhere in Myanmar, Thailand, Cambodia, Laos, the Philippines and southern China (Ueda 1960, Guang-chu 1987). Artificial induction of polyploidy has been tried in different countries. Ueda (1960) reported that in Japan a few seeds of *Phyllostachys reticulata* and *P. edulis* were treated with 0.2 percent cochicine. Seedlings showed normal growth.

Selection

Currently no systematic selection procedure has been employed to improve the planting stock of bamboos for afforestation and reforestation programs in the region. In the villages, people select bamboo for homestead planting mainly based on utility values. Varietal selection is barely being considered. There are four aspects of selection, as described below.

Species selection/introduction

Bamboos are often introduced, and specific species selected. Some species trials of exotic bamboos have been done in most countries of the region, but often somewhat sporadically and many opportunities for testing productive germplasm have been missed.

Provenance trial

Systematic investigations on the variability of growth and performance of different provenances of species have been carried out in Bangladesh, India and Thailand. Data are available from Bangladesh. The program involved survey of bamboo species and their uses, stock collection from different localities of the country and field trials for finding the best provenances. The selected species were: *Bambusa balcooa*, *B. vulgaris*, *B. longispiculata*, *B. tulda* and *Melocanna baccifera*. The tests were made in five field stations of Bangladesh Forest Research Institute (BFRI). Over the long period of bamboo cultivation in Bangladesh, it is probable that primitive cultivars suited to particular soil-climate combinations developed. For collection stock, the whole country was divided into three parts – north, central and south. In each of these parts, five major bamboo growing districts were taken as representative and from there 20-25 villages were treated as one unit of collection for each species. From the selected clump of a bamboo species, a number of offsets/rhizomes were collected as planting stock for the trial. Data were taken on diameter and height of culms, number of culms emerged per clump per year, and any other biological incidence such as flowering, disease, etc. Results showed that there exists significant variation among some provenances of each of the species. Further trials are underway to select promising high-yielding provenances.

No documented information are available on such trials in other countries of the region.

Bamboo clump selection

Very little information is available on the selection of candidate clumps of a bamboo species. However, in India, important bamboo species (*Bambusa balcooa*, *B. nutans*, *B. pallida*, *B. tulda*, *Dendrocalamus giganteus* and *D. hamiltonii*) have been looked at. Plus bamboos were selected from the natural forest and from village groves. The selection of plus bamboos have shown superiority over other bamboos (Beniwal and Singh 1988). Superior clones based on phenotypic characters (number of culms per clump, height, diameter and wall thickness of culms, length of internode, fibre length, and resistance to diseases and pests) can be selected from the adult wild populations and plantations.

Seedling selection

Very little information is so far available on seedling selection in bamboos. The relation between results obtained with seedlings and with mature clumps deserves systematic investigation. However, since bamboos are reported to be highly cross-pollinating species, it gives enormous opportunity for selection of superior seedlings having desired combination of characteristics after each gregarious/sporadic flowering (Venkatesh 1984, Tewari 1992). Desirable growth habit and healthy and vigorously growing nature of the seedlings may be considered as important criteria for seedling selection. During 1984, 17 and 10 vigorously growing seedlings of *Bambusa tulda* and *B. polymorpha*, respectively, were selected from populations of 10 000 and 5 000 seedlings raised in the nursery of BFRI. These selected seedlings along with average growing sibs were planted in the field to test their comparative growth performance. The growth of vigorous seedlings over normal ones was found to be two to five times higher. Banik (1991) also obtained a seedling of *Melocanna baccifera*, which has been exhibiting both sexual (flowers and seeds) and vegetative growth (culm emergence) simultaneously and did not die: a most desirable genotype. Kondas et al. (1973) and Banik (1980) reported seedling segregation of characters into grassy, grassy erect, and very erect in *B. bambos* and *B. glaucescens*, respectively. The erect and very erect types have shown fast growth rates, more vigour and rapid culm production.

Germplasm collections

Bamboos have been grown for more than hundred years in different botanical gardens (Indian Botanical Garden at Calcutta, Botanic Garden at Peradeniya of Sri Lanka, Singapore Botanical Garden, Kyoto Bamboo Garden of Japan, etc.) and parks of the region. In addition to their occurrence in the forests, bamboos have also been cultivated in homesteads of rural people. But the approach to systematic conservation of different bamboos species in the Indian subcontinent and Malayan Peninsula started about 25 years ago.

Systematic collection and centralization of the different bamboo species and their variants, if any, have been going on since 1972-73 inside the bambusetum of BFRI, Chittagong. So far, 33 species of bamboos under different genera (including exotic), and 55 flowering varieties under 12 species have been collected from different parts of villages and forests of Bangladesh. Each species.has been planted in one or more lines. Each of the lines comprises the propagules collected from different localities and sources. Records about morphology, growth pattern and seeding pattern of each clump of a species are being maintained.

To initiate work on the genetic upgrading of bamboos, the Forest Research Institute, Dehra Dun, India, developed research on germplasm collection and conservation. Three collection centres – one each in the east, north and south for temperate, subtropical and tropical species, respectively – with headquarters at Dehra Dun were initiated and involved about 100 species (Varmah and Bahadur 1980).

Efforts have also been initiated by the National Bureau of Plant Genetic Resources (NBPGR), New Delhi, India, and its stations in Trichur, Shillong and Ranchi, as well as for hill region (Arunachal Pradesh Centre) under the Indian Council for Agricultural Research (ICAR) to collect and build up genetic diversity of bamboo for evaluation and maintenance. Germplasm collection are being established for genetic evaluation at the New Delhi, Trichur and Ranchi centres (Kochhar et al. 1990)

Other, more botanic garden type collections have been established in China, Indonesia, Malaysia, the Philippines, Sri Lanka and Thailand with major support from IDRC.

Propagation through seeds

Seed characters

As bamboos produce seeds after long time intervals, knowledge on seed propagation is very limited. However, depending on the availability of seeds, a few countries of the region have been conducting studies on germination, storage and seedling growth of different species (Table 2). Bamboo produces one-seeded fruits, known as caryopses, covered with a number of persistent glumes. The fruit of *Melocalamus compactiflorus* is as large as a "small wood-apple", and the fruit of *Melocanna baccifera* is "berry-like". However, in general, bamboo seeds are small and light.

Mature seeds drop on the ground and become exposed to predators – such as birds, specially chickens, and pigeons in homesteads, and rats, porcupines and wild boar in natural forests. Birds and squirrels also eat seeds while on the plant. Only careful collection can overcome the predator problem. Seeds can be collected both from clumps and from the ground. Generally, seeds produced in the early part (mid-February to May) of the season are healthy and more viable.

Except for M. *baccifera,* glumed seeds of all other species can be separated from debris and empty seeds by floating in water. As the seeds of M. *baccifera* are big and not covered with glumes, they can be separated easily from debris and unwanted materials.

Seed germination, longevity and storage

Seeds should be sown in polythene bags just after collection. Bamboo seeds germinate better under shade than in direct sunlight. Hence, bamboo seeds can be considered as negatively photoblastic (Banik 1991). The germination media (soil and cow dung in 3:1 ratio) should be wet, but not waterlogged. Seeds start germinating within 3-7 days of sowing and continue up to 15-25 days.

Usually seeds have a short viability, which lasts only for 1-2 months. Experimentation has shown that reducing seed moisture content and storage at reduced temperatures extend viability. It is expected that if techniques were standardized and implemented quickly after seed harvesting, many practical problems of seed handling will be solved.

Seedling nursing and management

Initially, seedlings do best in partial shade compared to direct sunlight. Complete shading over seedling is to be avoided. The emergence of shoots is successive. The new shoots are bigger and taller than older ones. The germinating plumules are very thin (1-2 mm dia.) in *Bambusa tulda* and thick (4-6 mm) in *M. baccifera.* Within 1-4 weeks plumules elongate rapidly into stems bearing single leaves arising alternately. The stems of *B. polymorpha*, *B. tulda* and *Dendrocalamus longispathus* are more or less woody in nature, but *M. baccifera* has a soft and succulent stem with vigorous growth. *M. baccifera* seedlings become most elongated (175 cm) and thick (0.8 cm, dia.) at three months of age (Banik 1991).

A rhizome system starts to develop in the seedling after 1-2 months of germination, and at young stage the rhizome movement is strongly geotropic. Therefore, in a nursery, roots and rhizomes of a seedling penetrate the neighbouring polythene bags of other seedlings, leading to damage at the time of transportation. Frequent shifting of seedlings from one bed to another helps minimize intermingling. Seedlings need regular weeding and daily watering.

Wild seedlings

Wild seedlings of bamboo are often seen just below the flowering mother clumps. Appearance of seedlings is very profuse, often forming a thick mat. These dense seedlings compete for survival and may be thinned to minimize competition (Banik 1989, 1991). Wild seedlings can be collected and brought to and transplanted into the nursery. At the beginning, seedlings have to be kept under shade for 3-5 days for hardening; thereafter, partial shade is necessary. Two to four leaf stage of wild seedlings of *B. tulda* and *D. longispathus* is best for collection, while in the case of *M. baccifera,* germinating seedlings are the best. For better survival, less than one-year old seedlings should not be transplanted to the field.

Vegetative propagation

A complete bamboo plant consists of three morphologic structures – the aerial part (the culm) and the two underground parts (the rhizome and root). A bamboo propagule must develop all the morphologic structures – the leafy axis, rhizome and root. Failure in development of any of these leads to complete failure of a bamboo propagule (Banik 1980). Because of the scarcity of seeds, bamboo is generally propagated by various vegetative methods. These are:

1. Clump divisions - offsets, rhizome
2. Whole culm cutting
3. Layering
4. Culm-segment cutting
5. Branch cutting
6. Macroproliferation.

All these methods have been studied in different countries of Asia. Each country has developed a number of propagation methods suitable for its own bamboo species (Table 4).

Tissue culture

Tissue culture research on bamboos has been going on for some time in laboratories in Bangladesh, China, India, Hongkong, Nepal, the Philippines, Singapore and Thailand, and has accelerated in the 1980s.

Since this report was written, an updated review was made by Zamora (1994) and an IDRC publication (Ramanuja Rao et al. 1990) has provided practical details.

In vitro propagation techniques have been sufficiently developed for commercial applications, with *Dendrocalamus asper, D. strictus, D. hamiltonii, Bambusa bambos* and *B. tulda* being the major species targeted. Research has also looked at over 70 other species.

Continued sharing of knowledge across the region is necessary in order to employ suitable micropropagation methods for raising rural and industrial plantations.

Hybridization

Natural hybridization may take place when simultaneous flowering occurs among different species of bamboo in the same region. At the BFRI bamboo collection, for instance, clumps grown from seeds of *Dendrocalamus longispathus* collected from the forests have shown morphological characters that are different from those normally found in the species (Hasan 1979). A few clumps showed culm sheaths of *Gigantochloa nigrociliata* with normal culm form and bud characters of *D. longispathus*. One clump showed branching and long internodal characters of *Neohouzeaua dullooa* with the bud characters of *D. longispathus*. Thus, it seems that natural hybridization had taken place.

Long ago, there were unsuccessful attempts to hybridize sugarcane with bamboo (Venkatraman 1937). Studies (Rao et al. 1969) indicated that fertilization between bamboo and sugarcane gametes did take place, but the embryo and endosperm did not undergo further development. During 1962, in Hunan Botanical Garden, China, a hybridization study between two flowering bamboos, *Bambusa textilis* x *B. sinospinosa*, was carried out. The hybrid grew well. Up to 1987, hybridization trials had been done on 21 groups comprising four genera and seven species of bamboos (Guang-chu and Fu-qiu 1987). In most of the cases, hybrid production was successful. Some of the new hybrids had good growth and have proved better in mechanical properties than

Table 4: Conventional propagation techniques developed for bamboo species in different Asian countries

Species	Propagation techniques					
	Seed/ Sdl	McPrl	CulmCt/ Split ClCt	Marcot/ Grdly	PrBrCt/ BrCt	Offset/ Rhizome
Bambusa bambos	Bd, In, Ph, Th	Bd, In	In, Pk	-	-	Bd, In
B. balcooa	-	In, Np, Bd	-	-	Bd, In	Bd, In
B. blumeana	-	-	Ph	Ph	Ph	Ph, Th
B. glaucescens	Bd	Bd	-	-	-	Bd, In
B. longispiculata	-	-	-	-	-	Bd, In
B. nutans	-	Bd	-	-	-	Bd, In
B. pervariabilis	Ch	-	Ch	Ch	Ch	Ch
B. polymorpha	Bd	-	In	-	Bd	Bd, In
B. textilis	Ch	-	CH	-	Ch	Ch
B. tulda	Bd	Bd, In	In	-	-	Bd, In
B. vulgaris	-	-	In, Ph, Th	Bd, Ph	Bd, Ph	In, Bd
Dendrocalamus asper	-	-	Id	-	-	Ph, Th
D. brandisii	In, Th	-	Id	-	-	In, Th
D. giganteus	-	-	In	Bd	Bd	Bd, In, Th
D. merrillianus	-	-	Ph	-	Ph	Ph
D. hamiltonii	In	In	Np	-	-	Bd, In, Np
D. longispathus	Bd	In	Bd	-	-	Bd, In
D. strictus	Bd, In, Sl, Th	Bd, In	In, Pk	-	Bd, In	Bd, In, Np
D. latiflorus	-	-	-	-	Ph	Ph, Th
Gigantochloa aspera	-	-	Ma, Ph	-	-	Ma, Ph, Th
G. levis	-	-	Ma, Ph	-	-	Id, Ma, Th
Lingnania chungii	-	-	Ch	-	Ch	Ch
Melocanna baccifera	Bd, In	-	-	-	Bd, In	Bd
Neohouzeaua dullooa	Bd	-	Bd	-	Bd, In	-
Phyllostachys sp.	Ch, Jp	-	Ch, Jp	Ch, Jp	Ch, Jp	Ch, Jp
Schizostachyum lumampao	Ph	Ph	-	Ph	Ph	Ph
Thyrsostachys siamensis	Th	Bd	-	-	-	Bd, In, Th

Note:

Propagation techniques

Sdl = seedling McPrl = macroproliferation Culm Ct/Split ClCt = culm cutting/split culm cutting Marcot/Grdly = marcotting/ground layering PrBrCt/BrCt = Prerooted and prerhizomed branch cutting/branch cutting

Countries

Bd = Bangladesh Ch = China In = India Id = Indonesia Jp = Japan Ma = Malaysia Np = Nepal Pk = Pakistan Ph = the Philippines Sl = Sri Lanka Th = Thailand the parents. More recently, Guang-chu and Fu-qiu (1994) developed a new bamboo clone for quality shoot production. The methods used are introduction of good bamboo species for hybridizing with local Chinese species and selection of excellent clones from the hybrid combination. The result showed that:

(a) The hybrids of *Dendrocalamus latiflorus* x *D. hamiltonii* and *D. latiflorus* x *Sinocalamus stenoauritus* have had success and the shoots have no bitter taste.

(b) The nutrient contents, total amino acids and the essential amino acids in the shoots of *Bambusa pervariabilis* x *D. latiflorus* are higher than that in other species; the shoot yield is high and the processing properties are good.

It has been reported that success was better when crossing was made between two closely related species. Distantly related species may hybridize but their offspring grow abnormally, from which a desirable hybrid can hardly be chosen.

During 1984-85, both *Bambusa bambos* and *B. tulda* flowered in the BFRI bambusetum in Chittagong, Bangladesh. A trial was made to cross these two species. A number of hybrid seeds were obtained from the cross. Seedlings were raised and planted in the field station to evaluate their characters. Some hybrid seedlings showed mixed characters of both species. Some individuals developed thorns, a character of *B. bambos*, and also the big sized leaves and culm-colour of *B. tulda*.

No published reports on the success of artificial hybridization in bamboos are available from other countries of the region.

Mutation

Very little is known on mutation studies in bamboo. Guang-chu (1987) reported that *Bambusa vario-striatus* is a natural mutant, because the species has an unusually large chromosome number of 2n=96. In Japan, Ueda (1960) tried to induce mutation artificially in bamboo. He treated a few seeds of *Phyllostachys reticulata* and *Bambusa bambos* with X-rays. The success was not reported. Kapoor and Sharma (1992), in India, irradiated the seeds of *Dendrocalamus strictus* with gamma rays and obtained an early flowering mutant. Recently, at BFRI, seeds of *B. bambos* have been irradiated with gamma rays at 10, 20 and 30 krads. Seeds mostly germinated with 10 krads and little with 20 krads. The seedlings were planted in the field. Some clumps showed bushy and dwarf growth forms, some did not develop any thorns on the branches unlike the normal plants of the species, and one clump had very small sized leaves with light, wavy margins.

GENETIC IMPROVEMENT PLAN

Objectives

Forest trees are not usually cultivated by villagers in their homesteads. The national government of each country raises public forests only on the land which is not used for agricultural farming. On the other hand, people grow bamboos in homestead and on marginal lands. In the last two decades, agroforestry activities have been gaining momentum in villages of Asian countries. In addition to its forestry importance, bamboos are a major element in social forestry and have significant socio-economic impacts. They are treated as an important multipurpose crop component in the agroforestry system. Hence, bamboo has its specific client-oriented achievement needs and the objectives differ from conventional forest trees. Objectives include needs to:

1. Identify new useful, productive and socially acceptable bamboo species from exotic sources and natural populations.

2. Establish species trials of both indigenous and exotic commercial species for selecting the most suitable species for introduction and domestication.

3. Select suitable provenances/clones for improving the present yields. Higher biomass yields, production of palatable edible shoots with excellent canning quality, resistance against pests and diseases, and durability of felled bamboo against the borer or termite attack etc. are major selection criteria.

4. Develop and/or adopt dependable easy techniques of multiplication of selected higher yielding species/provenances/clones for raising plantations in both forests and villages.

5. Conserve bamboo germplasm *in-situ* and in *ex-situ* plots at national and regional levels to preserve the genetic diversity base.

6. Develop a source of frequent or regular seed production through collection and centralization of different "flowering genotypes" of a species, especially for those species which seed regularly.

7. Generate variability through application of biotechnology, hybridization, mutation and polyploidy research. This might be helpful in seeking lines tolerant of harsh environmental condition.

Some of the objectives can be immediately achieved through adoption of available technology. Necessary attention should be paid in the modification of technology based on different socio-economic needs of each member country of the Network.

Bamboos usually do not seed annually and therefore, conventional progeny tests are not easy. It is not always possible to test and measure heritability of desired characters in the progenies of selected individual mother clumps of a bamboo species. Hence, any planned hybridization program aimed at combining different desired characters in a hybrid and generating variability in the offspring is also very difficult.

It is also salient to recall that the scope of large-scale bamboo plantation is limited by the non-availability of bamboo seeds, and hence the past emphasis to develop suitable propagation techniques for large-scale man-made bamboo plantations.

Strategies

Two main strategies are proposed for enhancement: (a) immediate and short-term strategy, and (b) long-term strategy.

Immediate and short-term strategy (Figure 2)

Presently, a shortage of bamboo supply exists in most of the countries, and the gap between supply and demand will further widen in the future. To meet the ever-increasing demands, large-scale plantations with traditional high-yielding species and clones should be raised.

In the short-term strategy, the major activities regarding breeding may rely on and consist of the following:

1. Exploration of diversity, identification of ideal species, and mapping their natural range and description of phenotypic variations throughout the range;
2. Selection of species/provenances/individuals having desired qualities;
3. Mass propagation of desired individuals for reforestation purposes; and
4. Conservation and maintenance of germplasm for further use.

All these steps can go simultaneously, and steps 2 and 3 will bring immediate gain in improvement.

Long-term strategy (Figure 3)

The long-term strategy aims at maximization of genetic gains. There should be continuous search for genetic variabilities and their maintenance. This is essential for the success of future selection to meet the new selection criteria which might be brought about by, for instance, government policy and changes in end-use patterns.

In parallel, attempts should also be made to establish seed stands of bamboo in each of the countries, especially in the Malayan Peninsular zones as some bamboo species (e.g. *Schizostachyum brachycladum*) of this zone flower frequently. Variation in flowering (sporadic, irregular, gregarious) in the clumps are reported to be the expression of different pedigree and might have evolved naturally. Exploration, collection and centralization of such flowering genotypes of a species will possibly develop a source of frequent or regular seed production.

Re-establishment and induction of genetic variability should be pursued through biotechnology, polyploidy, hybridization and mutation research (Figures 3 and 4).

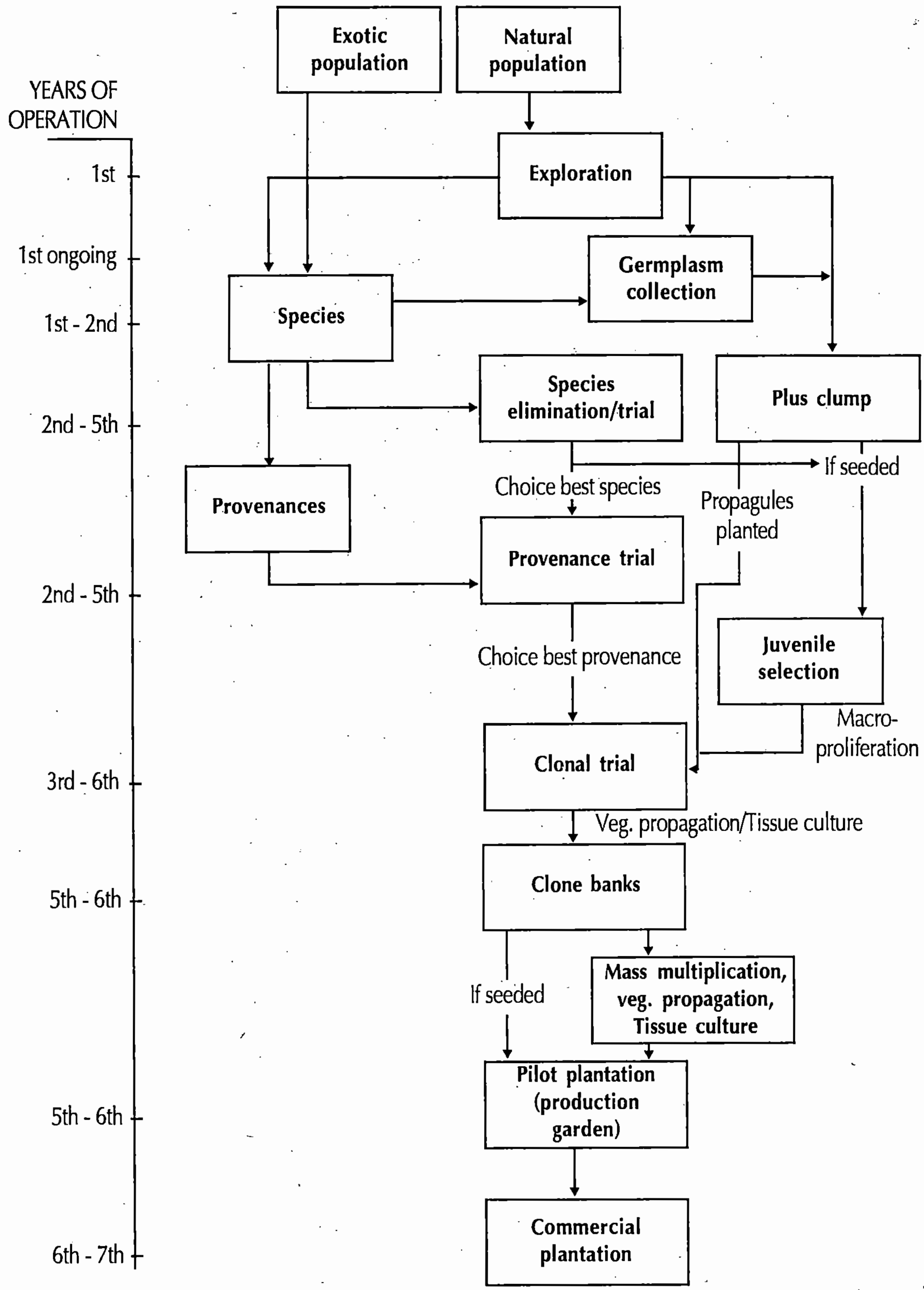

Fig. 2: A short-term plan for the improvement of bamboos

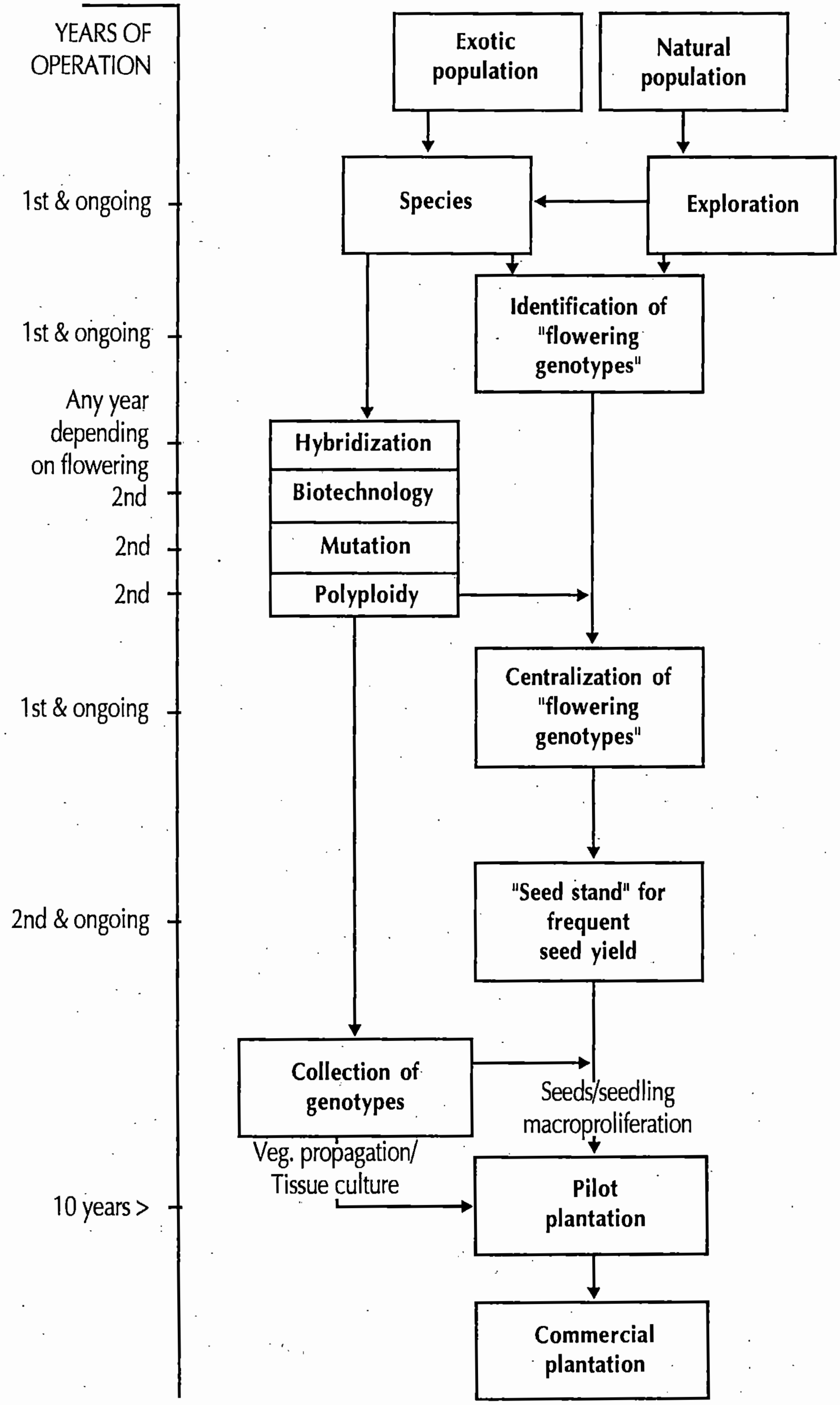

Fig. 3: A long-term plan for the improvement of bamboos

Breeding

Some constraints that exist in the basic knowledge of bamboo breeding are discussed below:

- Scarcity of basic genetic information: Bamboo is a much used but scientifically little known crop. Hardly any information is available on the physiology of late flowering, reproductive biology, gene action and genetic control over the desired characters, reactions and responses to stress conditions, etc.

- Confusion in identity: In many cases, the taxonomy and systematic position of bamboo species are questionable. Herbarium specimens contain mainly leaves, flowers and caryopses (if available). Other material such as culm sheaths, branch complements, stem surfaces, rhizomes are important but rarely or never collected.

- Lack of reproductive materials: Seeds are the major reproductive materials for higher plants. But bamboo generally flowers after a long period and then dies. So seeds are not always available for production of planting stocks. Alternatively, vegetative propagation methods have to be used. Lack of regular flowering is also a major constraint for hybridization works.

Therefore, a breeding program for bamboos needs a different outlook than conventional improvement work through clonal seed orchards and hybridization. In the plan, more emphasis will be given to selection breeding through exploring the existing natural variability. The classic stages of genetic resources development may be followed also in bamboo breeding: exploration, evaluation, selection and multiplication.

Selection

Forest crops, especially bamboo, have only recently or never been domesticated, selected or bred. As a result bamboos are still largely wild. They possess enormous natural variability, which the breeder can profitably utilize to improve productivity.

Bamboos, in habit, vary from strictly erect, erect with pendulous tips, or ascending, through broadly arched to clambering.

In a population, a number of categories of variation exist which can be broadly grouped into those related to species, geographic sources (provenances) and genotypes.

The following characters can be considered during selection of bamboos on the basis of specific end-uses. The names of some suitable species are listed.

For structural and construction applications

Selection criteria:

- Erect, straight and stout culm.
- Tall and large-sized (diameter 8-25 cm) culm.
- Thick walls (more than 1.0 cm), to solid internodes.

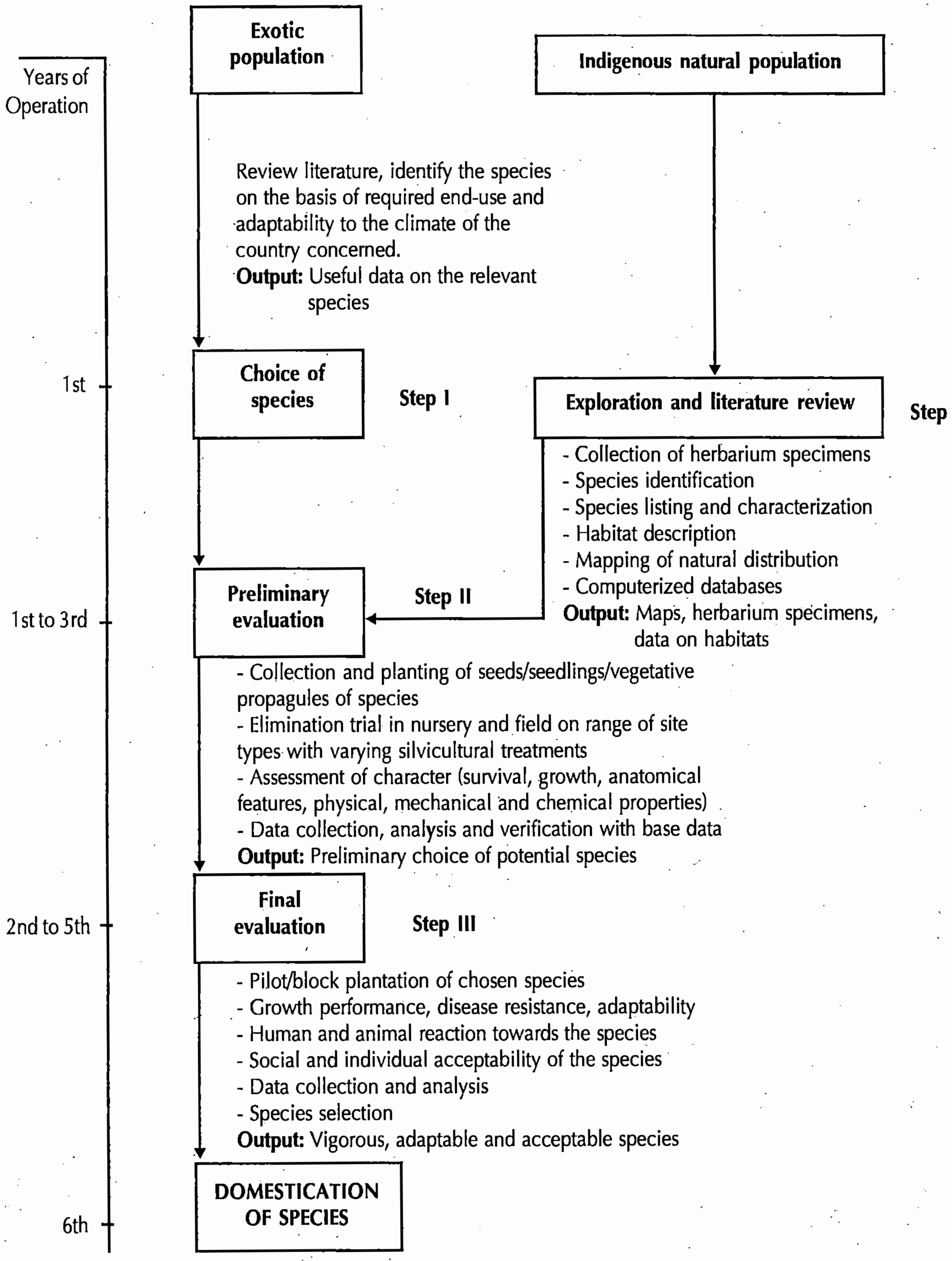

Fig. 4: Flow-chart showing the necessary path for domestication of bamboo species

- Comparatively shorter internodes with siliceous cover.
- Durability to powder-post beetles and fungal attack.
- Good response to preservative treatment. The large diameter metaxylem vessels in bamboos are the main channel for solution to penetrate in the longitudinal direction, and size of vessels is the most important factor that affects permeability.
- Higher density of culm wood.
- Low moisture content and shrinkage value.
- High number of vascular bundles per mm^2.

Some species:

Bambusa bambos, B. balcooa, B. blumeana, B. vulgaris, Dendrocalamus asper, D. giganteus, D. membranaceus, D. strictus, Gigantochloa apus, G. levis, Schizostachyum brachycladum, S. zollingeri.

For thatching, walling, roofing, handicrafts and novelty items

Selection criteria:

- Erect to clambering.
- Small to medium-sized culm diameter (usually 3-10 cm), smooth, less branched and not throughout.
- Thin wall (usually less than 1.0 cm).
- Comparatively long internodes (usually 0.3 to more than 1.0 m) with shiny skins.
- Durability to powder-post beetles and fungal attack.
- High value of modulus of elasticity (more than 150 000 kg/cm^2).
- Good splitting ability into fine strips and veneer.

Some species:

Bambusa bambos, B. blumeana, B. tulda, B. polymorpha, B. vulgaris, Cephalostachyum pergracile, Dendrocalamus asper, D. longispathus, Gigantochloa verticillata, G. atter, Melocanna baccifera, Neohouzeaua dullooa, Ochlandra stridula, Schizostachyum brachycladum, S. lima, S. lumampao, S. zollingeri, Thyrsostachys siamensis.

For pulp, paper and rayon

Selection criteria:

- Should have vigorous growth and maximum biomass production.
- Easy to chip.
- Less in silica, lignin and extractive contents and higher in cellulose.
- Long fibres (usually more than 2.0 mm), higher length-to-width ratio, and high fibre tissue ratio.

Some species:

Bambusa bambos, B. tulda, B. vulgaris, Dendrocalamus hamiltonii, D. longispathus, D. strictus, Gigantochloa asper, Melocanna baccifera, Ochlandra travancorica.

For edible shoots

Selection criteria:

- Shoot should be edible.
- More open nature of clump for ease in shoot harvesting.
- Non-thorny with less branches or mostly up to mid-culm.
- Wider range of culm emergence period.
- Zero or low natural mortality of shoots at juvenile stage.
- Resistance to pests and diseases.
- High number of shoot production per clump.
- Less amount of covering sheaths in relation to total biomass of shoot, less hairs and bristles on the sheaths, easy to remove sheaths.
- Succulent and palatable shoot with common vegetable smell, no astringency or bitterness.
- Higher nutritious value.
- Easy to boil and cook.
- Good storage and canning capability.

Some species:

Bambusa blumeana, B. polymorpha, Dendrocalamus asper, D. latiflorus Gigantochloa asper, G. levis, Melocanna baccifera, Phyllostachys edulis, S. brachycladum, Thyrsostachys siamensis.

Procedures for domestication and selection of useful and productive species/provenance/genotypes are shown step by step, along with the expected output of each step, in Figure 4.

Collection of propagules from exotic sources is sometimes difficult, as most of the time seeds are not available. Other types of propagules, such as offsets, branch cuttings and culm cuttings, have to be collected. Quarantine procedures for transportation of such materials from one country to another are always lengthy and usually takes several days. During this time, in most cases, propagules become dry and die, necessitating smooth and quick transportation between the donor and recepient countries.

Species trials

The differences among most of the traditionally cultivated bamboo species are well documented and their uses are also known. However, for the introduction of a species one must identify the species with desired end-use. Species require to be selected based on need and habitat suitability. Ten important bamboo species with their major traditional uses are listed in Table 5. Countries suggested for species trials are also listed.

After identification of a number of species for particular desired end-uses, their performance has to be tested through multilocation trials. A randomized complete block design with 3-5 replication may be used. Each plot may contain 25 propagules. Each species or provenance is represented only once in each block and the block is replicated 3-5 times.

Table 5: Some important bamboo species with their major traditional uses and possible countries for species trials

Species and major uses	Countries for species trials
1. *Bambusa bambos* (construction, pulp, edible shoot, cottage industry)	Indonesia, Malaysia, Philippines, Pakistan
2. *B. blumeana* (construction, pulp, edible shoot, cottage industry)	Bangladesh, India, Sri Lanka
3. *B. vulgaris* (construction, pulp, cottage industry)	Bangladesh, Bhutan, Nepal, Pakistan,
4. *Dendrocalamus asper* (edible shoot, cottage industry)	Bangladesh, Bhutan, India, Nepal, Sri Lanka
5. *D. latiflorus* (construction, edible shoot, furniture)	Bangladesh, Bhutan, India, Indonesia, Malaysia, Nepal, Sri Lanka, Thailand
6. *D. strictus* (pulp, construction, cottage industry)	Bhutan, Pakistan, the Philippines
7. *Gigantochloa levis* (edible shoot, construction, pulp)	Bangladesh, India, Sri Lanka
8. *G. verticillata* (pulp, construction, edible shoot)	Bangladesh, India, Malaysia, the Philippines, Sri Lanka
9. *Melocanna baccifera* (pulp, rayon, construction, edible shoot)	Bhutan, Indonesia, Malaysia, Nepal, the Philippines, Sri Lanka, Thailand
10. *Schizostachyum brachycladum* (construction, edible shoot, continuous flowering)	Bangladesh, India, Sri Lanka

Survival and growth data (number of culms emerged, culm length and diameter, clump girth) have to be collected from each clump annually during December to January. By analysing the data obtained after the second or third year of the trial, it is normally possible to select the best species for further provenance trials.

Provenance trials

Most species with large natural ranges are likely to be genetically variable. No one seed lot or vegetative propagule can be considered as representative of the entire species. Variation may be present in populations (provenances) or individuals plants.

There are few bamboo species growing in common in many countries of the region. Among them are the important multipurpose traditional species: *Bambusa bambos*, *B. blumeana*, *B. vulgaris*, *Dendrocalamus hamiltonii*, *D. strictus*, *Gigantochloa levis*, *Neohouzeaua dullooa*, *Schizostachyum brachycladum* and *Thyrsostachys siamensis*.

Some variations among different geographical sources of the three most common bamboo species of the region, are discussed below.

(a) *Dendrocalamus strictus*: It is one of the most widespread bamboos in the Indo-Malesian zone. The species growing in the drier western part of India has comparatively solid culms and in other parts the culms are hollow with thick walls. Culms vary in size, according to climate: 6-15 m high and 2.5-7.5 cm in diameter (Prasad 1948).

Three growth forms of clumps can be recognized in India:

1. Common type: Found everywhere, ordinary form producing medium-sized hollow to solid culms.
2. Large type: Found in the forests of United Provinces (now Uttar Pradesh), in Bihar and Orissa; has practically no side branches to a great height and seldom shows sign of congestion. The culms are large with long, straight and smooth internodes.
3. Dwarf type: This small type only exceptionally forms culms. It is typically found in Balaghat of Central Provinces (now Madhya Pradesh), where it is known as karka.

Depending on the geographical source, the duration of interseeding period also varies in *D. strictus*. In southern India (Karnataka) the estimated interseeding period is 24-28 years (Kadambi 1949); in northern (Uttar Pradesh), eastern and central India, 40-44 years (Kadambi 1949, Gupta 1952); and in western India (Hoshiarpur of Punjab) 65 years (Mathauda 1952). The introduced *D. strictus* in Bangladesh also has 45 years of interseeding period, suggesting that original stock came from the central and eastern India (Banik 1981).

(b) *Bambusa bambos*: It is another common species growing throughout Sri Lanka, Myanmar, Bangladesh, Thailand and India, except in the Himalayan and sub-Himalayan region and the valleys of the Ganges and Indus. Two major growth forms of the species have been recognized on the basis of geographical locations.

1. Tall, comely, large-culm type commonly found in the hills of South India, and
2. Dwarf, thickly branched and very thorny small-culm type found on the low hills of Orissa, lower Bengal and across to Myanmar, and also probably in Thailand.

(c) *Bambusa vulgaris*: This is a bamboo which is known only in cultivation and not recorded from any natural forests. Since time immemorial, the species has been commonly cultivated in most of the tropical and subtropical countries of South, South-East and East Asia owing to its versatile use. The species is also common in cultivation in the countries of Central America, as well as in some parts of South America and Africa. The growth forms of this species in all these areas are not the same. The species is extensively cultivated in rural areas of Bangladesh and has thus become a major construction bamboo of the country. During the last 15 to 20 years, the clumps of this species have been infected severely with blight disease nearly at an epidemic scale, creating shortage of the crop. Interestingly, no such disease has been reported from neighbouring India, Myanmar and other countries. Thus, *B. vulgaris* growing in Bangladesh is susceptible to the blight disease, while the species from other sources the species may be resistant to the disease. Multisite provenance testing could be one way of selecting suitable disease resistant provenances.

Individual clump selection (plus clump)

In selecting superior phenotypes from a species/provenance, the following desirable characters may be considered:

1. The clump should be healthy and not infected by a disease.
2. Branching mostly at the top and none or less at the bottom.
3. Somewhat open clump (not congested) for facilitating easy harvesting.
4. Wider growing period of culm emergence.
5. High number of culm production per clump.
6. No or low mortality at juvenile stage of culm emergence.
7. Succulent and palatable shoot.
8. Comparatively capable of growing if waterlogged or flooded.
9. Comparatively capable of growing in drier areas.
10. Easy to propagate vegetatively.
11. None or only partial death after flowering (part-flowering in nature).
12. Simultaneous sexual (seeding) and vegetative growth (shoot production).
13. High capacity of viable seed production.
14. Any other character(s) that are desired for specific end-use.

Juvenile (seedling) selection

Natural seedling populations of bamboos showing genotypic diversity may afford an opportunity for selecting, as clones, individual superior plants (McClure 1966). Therefore, early recognition of progenies or individuals with a high genetic yield potential would be a great advantage. As the evaluation will be done among juvenile material, the process may be termed juvenile (seedling) selection. The following procedures were used for selecting the better seedling clones of *Bambusa tulda* and *B. polymorpha* in Bangladesh; the same procedures may be followed in other countries for seedling selection.

1. Collect seeds from a population of flowering desired species. For seedling selection, avoid seed collection when only one or two clumps flower.
2. Raise minimum of 20 000 seedlings in the same potting mixture, using similar containers, under partial shade. In general, bamboo seeds are negatively photoblastic. After 3-4 months, seedlings are to be shifted to direct sunlight. Try to minimize age effects on growth.
3. Provide all the seedlings as far as possible similar nursery treatments – weeding, watering, light, etc.
4. At three months, start taking growth data on a randomly selected 200 average seedlings out of the total population. Observations are to be taken on overall health of the seedlings, length, diameter at the collar zone of the shoots and number of leaves. Measure the leaf area of at least three leaves taken from base, middle and top of the crown, as well as any other interesting visible characters. Mark the 200 seedlings as A_1, A_2, A_3 ...., A_{200}. They represent the total population. Find out the average values of all the observation with standard errors.
5. Repeat the data recording quarterly at least up to one year for the same two hundred seedlings.

6. When the population is nine months old, observe carefully all the individuals in the population for their overall look. Identify healthy seedlings having many and tall shoots.
7. On these identified seedlings, take data as done with the 200 randomly selected average seedlings.
8. Identified healthy seedlings are then placed separately in the nursery by the side of the total seedling population.
9. Take growth data again from the identified vigorously growing seedlings and also from the previously randomly selected 200 seedlings.
10. Assess the growth data and select those seedlings from the identified seedlings which scored highest values for all parameters in comparison with the randomly selected 200 average seedlings.
11. Suppose 10 vigorously healthy seedlings are selected. Mark them serially as H1, H2 .....H10.
12. Multiply each of the healthy seedlings through macroproliferation techniques.
13. Try to obtain at least five multiplied individuals from each of these 10 selected seedlings. As each of these five individuals are clones of the same seedling, they should be marked H1/1, H1/2, H1/3 and so on. This indicates that all the five individuals are clones of healthy seedling number one (H1).
14. Multiply similarly any 10 seedlings from the randomly selected 200 average seedlings and mar them accordingly.
15. At 24 months, five plants of each healthy (H) and average (A) growing seedlings have to be planted in a randomized design in the field.
16. Assess the growth of each of the individuals up to 5 years.
17. Select those "H" clones which show better growth over "A" clones even after 5 years of plantation.

Clonal propagation

True-to-type progeny with genetic qualities identical to the mother plant are obtained through vegetative propagation. New technologies – such as prerooted and prerhizomed branch cuttings, split culm-cuttings, etc. – have substantially cut down the cost of bamboo plantations when compared with those raised from conventional planting stocks of rhizome and offsets. Further applied research is needed to develop easy and cheap mass-scale propagation. In this context, the possibility of producing rooted branch node-cuttings, 1-5 cm long, is worth investigating.

So far, the success of bamboo tissue culture has been achieved mainly with explants like seeds, seedlings and immature embryos. Such explants do not satisfy the objective of cloning mature and selected elite bamboos. *In vitro* culture of vegetative explants (not seed or seedling) is a prerequisite for clonal micropropagation of selected species and plus clump. Somatic embryogenesis and micropropagation through nodes and seeds can be used for mass-scale multiplication of some bamboo species (Figure 5). However, the success in *in vitro* shoot production from mature vegetative explants (such as mature branch nodes) is limited to a few species and the protocols are also not well developed. Therefore, further studies are suggested.

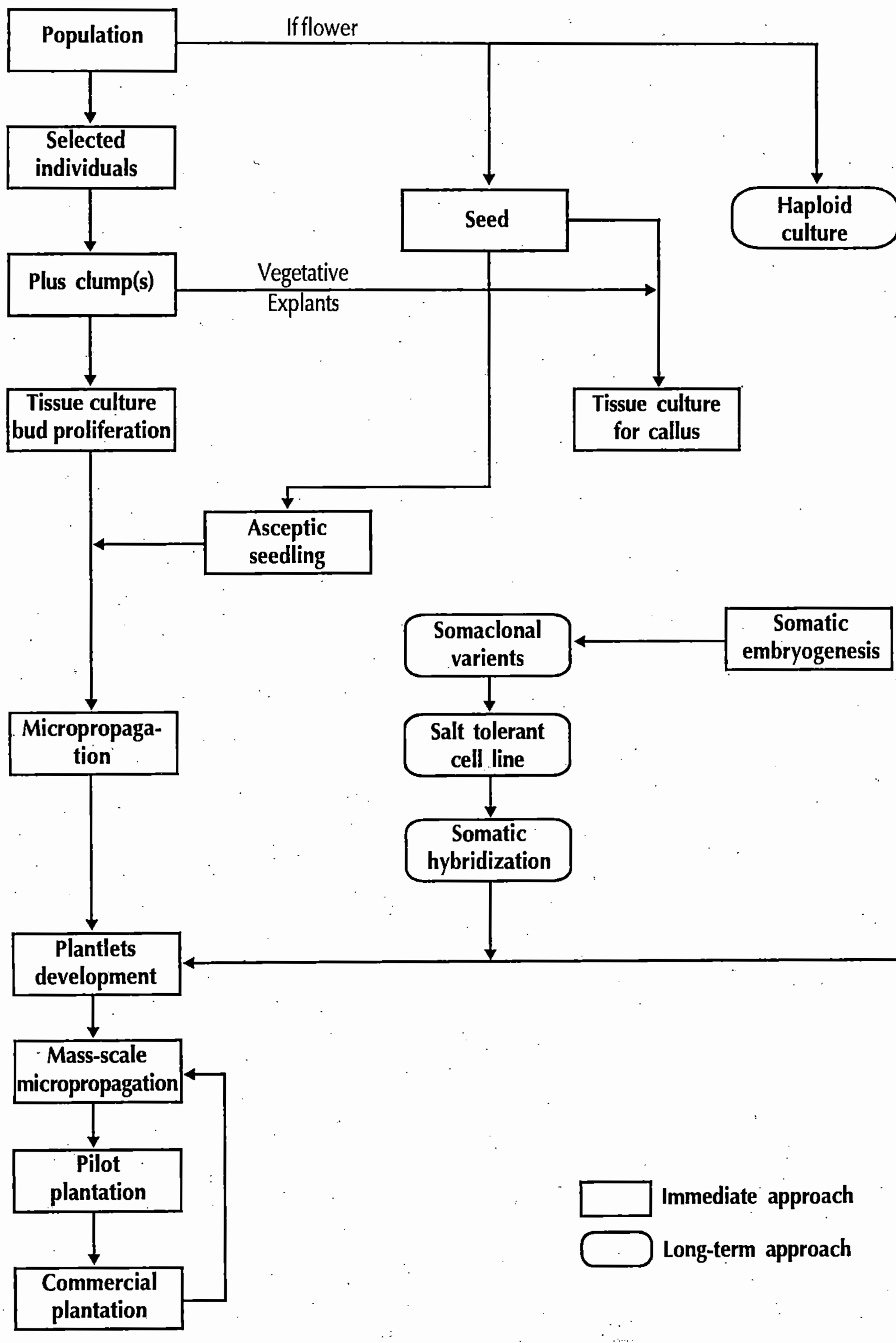

Fig. 5: Schematic representation of action plan for producing high-yielding varieties of bamboos

Clonal trials and maintenance

After selecting the suitable species, outstanding provenances and phenotypically superior individuals, they are to be multiplied asexually (both macro- and micropropagation). The propagules thus developed from one individual (ortet) source are the members of one clone. Accordingly, a number of clones may be obtained from one species/provenance.

The clones have to be evaluated in multilocational field trials. In each clonal trial, each set is to be planted in a randomized complete block design with six blocks, and each clone may be represented by a 10-propagule (10 clumps) row plot to get a total of 60 propagules per clone. Survival, growth rates, disease resistance and other desired characters in relation to end-use must be evaluated. After that, clones may be grouped into three categories: the best, the second best and rejects. The first two will be planted at 5 m spacing and maintained in a clonal bank for further study and multiplication.

Pilot plantation

Pilot plantations of a few hundred hectares may be established as an intermediate step before the commencement of a large-scale commercial plantation program, especially for propagules raised through tissue culture. In general, such plantations may demonstrate the viability of the technology to potential investors and farmers. Moreover, different cultural practices, including planting, maintenance, and harvesting, may also be demonstrated to growers. These plantations will also act as production gardens or clonal multiplication areas.

Since bamboo is a fast growing crop, the commercial plantation may be started within 1-2 years of the pilot plantation. Initially, the propagules may be collected from the clone bank and after a few years, large numbers of planting stocks can be raised from the pilot plantation.

Risks of a narrow genetic base of the clonal plantation can be minimized by including a fairly large number of genetically unrelated clones.

Long-term breeding program

This section looks at a long-term breeding program at the national level and within the frame work of a regional cooperative network.

Collection of flowering genotypes for seed stands

Variation in flowering periodicity has been observed and documented among the clumps under the same bamboo species. The following steps could to be taken to collect "flowering genotypes".

- Collect information regularly on the incidence and locality of flowering.
- Explore and visit both natural and planted populations of indigenous and introduced species, respectively, for locating and identifying the flowering clump(s).
- Diagnose the nature of flowering: sporadic flowering, part-flowering clump, complete flowering clump, gregarious flowering, etc. Under a given species, different clumps may exhibit flowering in different or the same locality in different or the same year.

- Each of the flowering clumps may be designated as a "flowering genotype" and labelled (for instance, in Bangladesh: *Bambusa tulda*/Shishak/1977, *Bambusa tulda*/Kaptai 1980, *Bambusa tulda*/Sylhet/1984, *Bambusa tulda*/Keochia/1989).
- Collect seeds/seedling/other propagules from the identified flowering clump(s).
- Raise seedlings and collect wild seedlings and other propagules. Mark each of them according to the mother flowering clump and maintain separately in the nursery. Group these planting stock according to the species.
- After one year of maintenance in the nursery, plant them (flowering genotypes) species wise in a suitable site.
- Plant the seedlings/other propagules in lines according to the seeding year under each species.
- Identify, and centralize in one common place, a number of "flowering genotypes" under different bamboo species.

Such centralized plots may be termed "seed stands" (Figure 3). Some bamboo species growing in different countries may flower at different times. It is worthwhile to collect these "flowering genotypes" of a species and plant them in a plot. In the next flowering time, they flower at a different time and thus seed yield will be more frequent.

Induction of variability through Biotechnology

Research on haploid culture, callus culture against stress conditions and development of tolerant cell line, etc. could started as a long-term genetic improvement program.

Hybridization

As flowering in bamboos is a rare phenomenon, it is difficult to take up any planned hybridization program aimed at combining the desired characters in a hybrid and generating variability to facilitate selection (Tewari 1992). However, there is enormous scope and possibilities of studies on the production of new bamboo hybrids because many bamboo species flower either annually (Anan 1987), sporadically or, in some cases, almost continuously (Holttum 1958).

The steps in hybridization have been described by Guang-chu and Fu-qiu (1991) for a number of Chinese species. With slight modification of their methodology, the following procedure may be tried for controlled hybridization studies in bamboos of the region.

Transfer of desired flowering mother plants of available bamboo species to a working nursery

↓

Group them either as male or female parents

↓

Artificial pollination
male X female

This requires selection of suitable time, selection of flower and thinning, and actual pollination time. The characters of the hybrid bamboo plants have to be recorded. A preliminary selection may be made at the seedling stage from vegetative growth, as well as from external and anatomical characters (for example, intensity of vascular bundles, amount of fibre tissue, etc.).

Through multilocation field trials, the characters of hybrids can be evaluated, and then the desired one(s) selected.

Cytogenetical study and induction of polyploidy

It is evident that aneuploids and triploids may be available in natural populations, and these deserve investigation. It will be worthwhile to search or experimentally produce tetraploids or triploids in bamboos to see whether changes in ploidy level brings any improvement in growth performance (Tewari 1992). Polyploidy breeding in bamboos needs concerted efforts to exploit vigour. Haploids can also be tried for further breeding work and to produce pure lines for further crossing and exploiting heterosis.

As cytogenetical information on bamboos is scanty, there is an urgent need for cytological studies. Meiotic studies on bamboos also need to be undertaken so that an understanding of seed fertility can be achieved.

SUPPORT PLAN

FORTIP, which operates as a network linking Asian countries, is in a unique position to address constraints of member countries. Such constraints include lack of sufficient trained personnel, necessary funds and the kind of institutional strength needed to undertake many specialized aspects of bamboo domestication and breeding. To achieve success, support is needed for:

1. Developing an information base;
2. Exchanging technologies of bamboo propagation and plantation;
3. Strengthening the technical facilities for propagation and improvement activities;
4. Exchanging germplasm and its conservation; and
5. Improving manpower development facilities.

(Editor's Note: The original report included many aspects of program support which are now the responsibility of INBAR. Since INBAR's inception in 1993, FORTIP has actively collaborated on bamboo research.)

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APPENDIX

Some bamboo species occurring in ten countries of the Indo-Malesian region
(+++ = very common, ++ = common, + = sporadic, - = not known or absent)

SPECIES	BANG	BHUT	INDI	INDO	MALA	NEPA	PAKI	PHIL	SRIL	THAI
Arundinaria debilis	-	-	-	-	-	-	-	-	++	-
A. densifolia	-	-	-	-	-	-	-	-	++	-
A. falconeri	-	++	-	-	-	++	-	-	-	-
A. floribunda	-	-	-	-	-	-	-	-	++	-
A. griffinthiana	-	+	-	-	-	-	-	-	-	-
A. hookerianus	-	++	-	-	-	-	-	-	-	-
A. japonica	-	-	+	-	-	-	-	-	-	-
A. maling	-	+	+	+	-	+++	-	-	-	-
A. racemosa	-	++	+	-	-	++	-	-	-	-
A. scandens	-	-	-	-	-	-	-	-	+	-
A. walkeriana	-	-	-	-	-	-	-	-	++	-
A. hookerjana	-	++	-	-	-	+++	-	-	-	-
A. microphylla	-	++	-	-	-	+	-	-	-	-
Bambusa alami	++	+	-	-	-	-	-	-	-	-
B. atra	-	-	+	+	-	-	-	+	-	-
B. bambos	+	-	+++	++	+	+++	+	+	+	+++
B. balcooa	+++	++	+++	+	-	++	-	-	+	-
B. blumeana	-	-	-	+++	+++	-	-	+++	-	++
B. burmanica	-	-	++	-	+	-	-	-	-	+
B. cornuta	-	-	-	-	-	-	-	+	++	++
B. glaucescens	+	-	++	+	+	-	-	-	-	-
B. longispiculata	+++	-	++	-	-	+++	-	-	-	+
B. montana	-	-	-	-	+	+	-	+	+	+
B. nepalensis	-	-	-	-	-	+	-	-	-	-
B. nutans	++	++	+++	-	-	+++	-	-	-	-
B. pallida	-	++	-	-	-	-	-	-	-	-

SPECIES	BANG	BHUT	INDI	INDO	MALA	NEPA	PAKI	PHIL	SRIL	THAI
B. polymorpha	++	-	++	+	-	-	-	-	-	++
B. ridleyi	-	-	-	-	++	-	-	-	-	-
B. tulda	+++	+	++	+	-	+	-	+	-	++
B. ventricosa	-	-	-		+	-	-	-	-	-
B. vulgaris	+++	+	+++	+++	+++	-	-	++	+++	++
B. wrayi	-	-	-	-	++	-	-	-	-	-
Borinda chigar	-	++	-	-	-	++	-	-	-	-
B. grossa	-	++	-	-	-	-	-	-	-	-
Cephalostachyum fuchsianum	-	++	+	-	-	-	-	-	++	-
C. latifolium	-	++	+	-	-	+	-	-	-	-
C. pallidum	-	+	++	-	-	-	-	-	-	-
C. pergracile	+	-	+++	-	-	+	-	-	-	+++
Dendrocalamus asper	-	-	-	+	++	-	-	++	++	+
D. brandisii	-	-	++	-	-	-	-	-	-	++
D. giganteus	+	-	++	-	+	++	-	-	++	++
D. hamiltonii	+	++	++	-	+++	+	-	-	-	+
D. hirtellus	+	-	+	-	-	-	-	-	-	+
D. hookerii	-	+	++	-	-	++	-	-	-	-
D. latiflorus	-	-	+	-	-	-	-	+	-	+
D. longispathus	++	-	++	-	-	-	-	-	-	++
D. membranaceus	+	-	+	-	-	-	-	-	++	++
D. patellaris	-	++	+	-	-	++	-	-	-	-
D. pendulus	-	-	-	-	+++	-	-	-	-	-
D. strictus	+	-	+++	+	+	++	+	-	+	++
Dinochloa maclelandii	-	-	++	-	-	-	-	-	-	++
D. pubiramea	-	-	-	-	-	-	-	++	-	-
Drepanostachyum falcatum	-	-	-	-	-	++	-	-	-	-
D. khasianum	-	++	-	-	-	+	-	-	-	-
Gigantochloa albociliata	-	-	-	-	-	-	-	-	-	+++
G. apus	-	-	-	++	+	-	-	-	-	++
G. atter	-	-	+	+++	+	-	-	+	-	-
G. hasskarliana	-	-	-	++	+	-	-	-	-	+
G. levis	-	-	-	++	++	-	-	++	-	-
G. ligulata	-	-	-	-	++	-	-	-	-	++

SPECIES	BANG	BHUT	INDI	INDO	MALA	NEPA	PAKI	PHIL	SRIL	THAI
G. maxima	-	-	++	+++	+	-	-	-	-	-
G. nigrociliata	++	-	+	++	-	-	-	-	-	-
G. ridleyi	-	-	-	-	++	-	-	-	-	-
G. scortechinii	-	-	-	-	+++	-	-	+	-	+
Himolayacalamus brevinodus	-	-	-	-	-	++	-	-	-	-
H. fimbriatus	-	-	-	-	-	++	-	-	-	
Melocalamus compactiflorus	+	-	+	-	-	-	-	-	-	+
Melocanna baccifera	+++	+	+++	-	-	-	-	-	-	-
M. humilis	-	-	+	+	-	+++	-	-	-	+
Neohouzeaua dullooa	++	++	++	-	-	+	-	-	-	+
Ochlandra stridula	-	-	-	-	-	-	-	-	+++	-
O. travancorica	-	++	++	-	-	-	-	-	-	-
Oxyteranthum stocksii	-	-	++	-	-	-	-	-	-	+
Phyllostachys aurea	-	-	+	+	+	-	-	+	-	+
Schizostachyum aciculare	-	-	-	-	+	-	-	-	-	++
S. brachycladum	-	-	++	++	++	-	-	+	-	+
S. grande	-	-	-	++	+++	-	-	-	-	++
S. jaculans	-	-	-	-	++	-	-	-	-	-
S. latifolium	-	-	-	++	+	-	-	-	-	+
S. lima	-	-	-	+	+	-	-	++	-	-
S. lumampao	-	-	-	-	-	-	-	+++	-	-
S. zollingeri	-	-	-	++	+++	-	-	+	-	++
Thamnocalamus aristatus	-	++	+	-	-	-	-	-	-	-
T. spathiflorus	-	+++	-	-	-	++	-	-	-	-
Thyrsostachys oliveri	+	-	+	-	-	-	-	-	-	+
T. siamensis	+	-	+	+	+	-	-	-	++	+++
Yushania nittakayamensis	-	-	-	-	+	-	-	++	-	-

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