Anatomy and Properties of Bamboo

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Abstract

The numerous alternatives in the use of bamboo depend on the unique properties of its culm. In order to understand the anatomical and chemical make-up and its ensuing mechanical properties, an attempt has been made to summarize the accessible information.

Anatomy

Gross anatomy: The properties of the culm are determined by its anatomical structure. The culm consists of internodes and nodes. At the internodes, the cells are axially oriented, whereas at the nodes, cells provide the transverse interconnections. No radial cell elements, such as rays, exist in the internodes. Within the nodes an intensive branching of the vessels occurs. These also bend radially inward and provide transverse conduction through the nodal diaphragms, so that all parts of the culm are interwoven. The outer part of the culm is formed by two epidermal cell layers, the inner appearing thicker and highly lignified. The surface of outermost cells are covered by a cutinized layer with a wax coating. The inner parts of the culm consist of numerous sclerenchyma cells. Any lateral movement of liquids is therefore much hindered. Pathways for penetration are thus only the cross ends of the culm and to a much smaller extent the sheath scars around the nodes.

The gross anatomical structure of a transverse section of any culm internode is determined by the shape, size, arrangement and number of the vascular bundles. They are clearly contrasted by the darker colored sclerenchymatous tissue against the parenchymatous ground tissue. At the peripheral zone of the culm the vascular bundles are smaller and more numerous, in the inner parts larger and fewer (Figs. 1, 2). Within the culm wall the total number of vascular bundles decreases from bottom towards the top, while their density increases at the same time. The culm tissue is mostly parenchyma and the vascular bundles which are composed of vessels, sieve tubes with companion cells and fibres. The total culm comprises about 50% parenchyma, 40% fibre, and 10% conducting tissues (vessels and sieve tubes) with some variation according to species. The percentage distribution and orientation of cells show a definite pattern within the culm, both horizontally and vertically. Parenchyma and conducting cells are more frequent in the inner third of the wall, whereas in the outer third the percentage of fibers is distinctly higher. In the vertical direction the amount of fibres increases from bottom to top and that of parenchyma decreases (Fig. 3) The common practice of leaving the upper part of a cut culm unused in the forest is therefore a waste with regard to its higher fibre content.

Parenchyma: The ground tissue consists of parenchyma cells, which are mostly vertically elongated (100 x 20 urn) with short, cube-like ones interspersed in between. The former are characterized by thicker walls with a polylamellate structure (Fig. 4); they become Iignified in the early stages of shoot growth. The shorter cells have a denser cytoplasm, thinner walls and retain their cytoplasmic activity for a long time. The function of these two different types of parenchyma cells is still unknown.

Of interest in the structure of parenchyma walls is the occurrence of warts in many taxa

See also recent GTZ publication: Bamboos – Biology, Silvics, Properties, Utilization by Liese, 1985 – Ed,

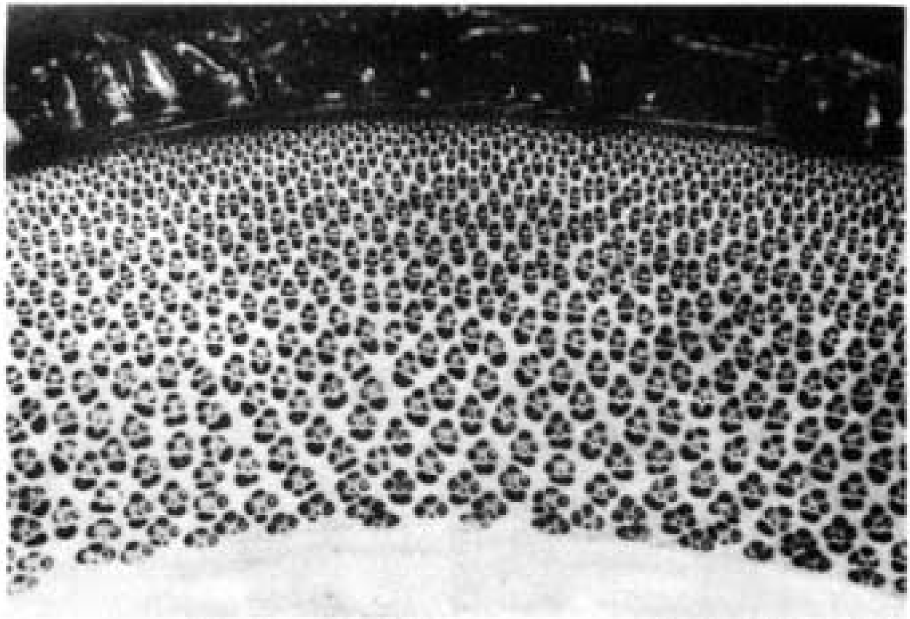

Figure 2. Overview of 6 culm section, Dendrocalamus giganteus.

Ftgure 2. Three-dlmenslonal view of culm tissue with vascular bundles.

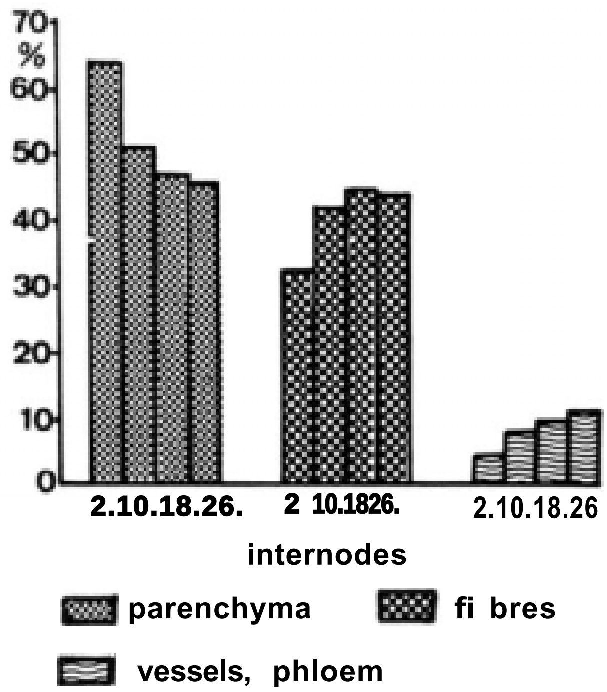

Figure 3. Percentage of cell type in the vertical direction of a culm; Cephalostachyum perqracile.

like **Bombusa**, ***Cephalostachyum, Dendrocalamus, Oxytenanthera,*** *Thyrostachys,* which have not been observed so far in the **parenchyma** of hardwoods. Genuine warts have to be carefully distinguished from cytoplasmic debris, which are also frequent in parenchyma cells after the death of the protoplast. Their distribution is variable from very dense to sparse. Among the species examined the parenchyma cells appear to possess a even higher number and density of warts than fibres and vessel members. Their size varies from 120 – 520 nm. The occurrence of warts in the lignified parenchyma cells of bamboo is perhaps an expression of the close association of lignin-like nature of warts, since warts have not been observed in non-lignified cells (Parameswaran and Liese, 1977).

Vascular bundles: The vascular bundle in the bamboo culm consists of the xylem with one or two smaller protoxylem elements and two large metaxylem vessels (40 – 120 urn)

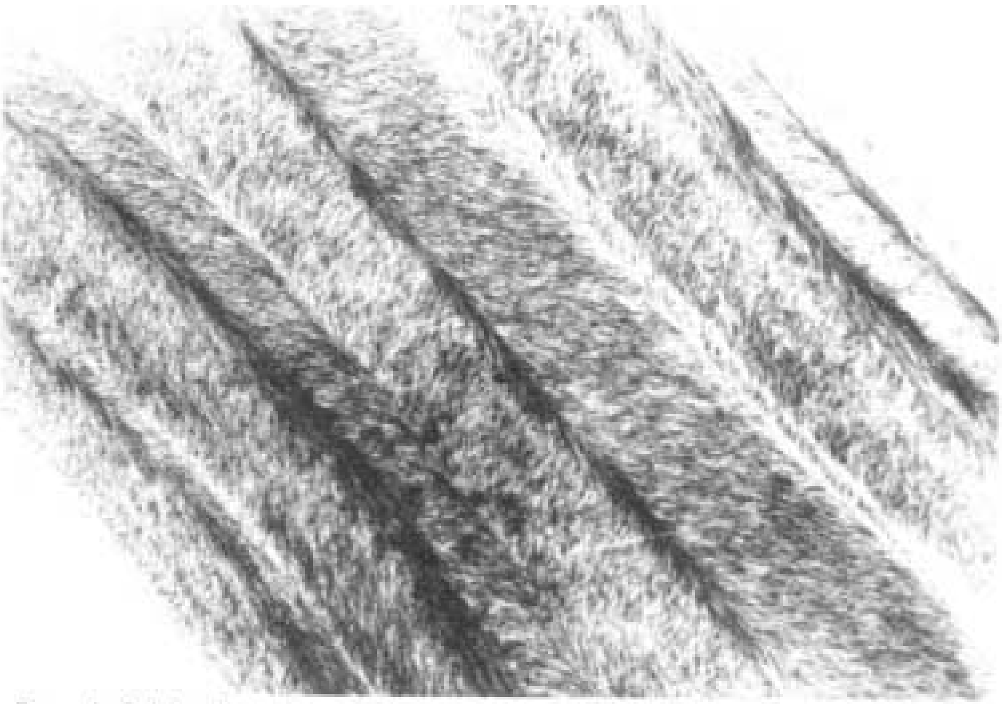

Figure 4. Polylamellate structure of a parenchyma cell wall. **Phyllostchys edulis**, 19.000 x.

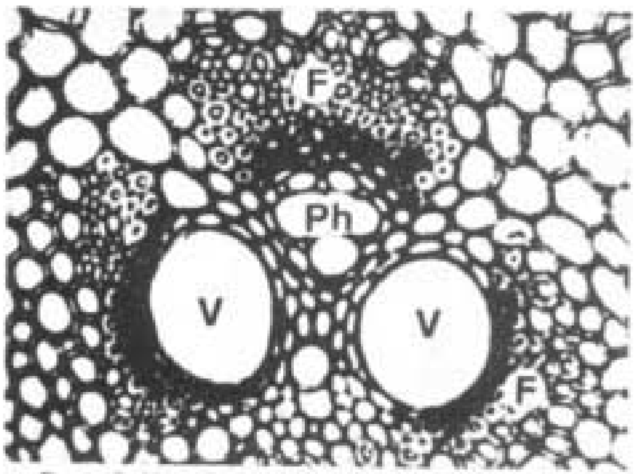

Figure 5. Vascular bundle with two large metaxylem vessels (V) and phloem (Ph) surrounded by fibres (F)

and the phloem with thinwalled, unlignified sieve tubes connected to companion cells (Fig. 5). The vessels possess large diameters in the inner parts of the culm wall and become small towards outside. These water conducting elements have to function throughout the lifetime of a culm without the formation of any new tissue, as in the case of hardwoods and softwoods with cambial activity. In older culms, vessels and sieve tubes can become partly impermeable due to depositions of gum-like substances, thus losing their conductivity which may cause death of the aged culms. The one or two tracheary elements of the protoxylem have mostly annular thickenings. They are local areas of stasis accumulating wall material, which are connected with each other by membranes in the early stages of development. During extension growth of the cell, they are disrupted.

The walls of metaxyiem vessels of bamboo are characterized by a middle lamella and a primary wall together with a well developed zonation of the secondary wall into Sl and S2. Whereas the Sl possesses a flat spiral arrangement of fibrils (90 – 95°) the S2 zone shows a slight deviation from the known fibril orientation in tracheids. The fibrils are arranged at an angle of 30 – 90° to the cell axis; also microlamellae are present with fibrils arranged in a fan-like fashion. This wall structure perhaps to be considered as "normal", is modified In some taxa like Oxytenatherd abysinica and Melocanna bambusoides to such an extent that a polylamellae construction results, resembling a parenchyma wall with the herringbone pattern of fibrillar arrangement whereby the number of layers are mostly restricted to two to four (Parameswaran and Liese. 1980). Warts have been observed in the metaxylem of vessels of *Oxytenanthera* nigrociliata, Melocanna bambusoides. Gigantochloa alter. f nigra. *Schizostachyum blumei.* and S brachycla dium. The pits of these vessels towards the surrounding parenchyma of adjacent vessel elements are slightly bordered. Their membrane consists of fibrils with a net-like texture, resembling hardwood pits,

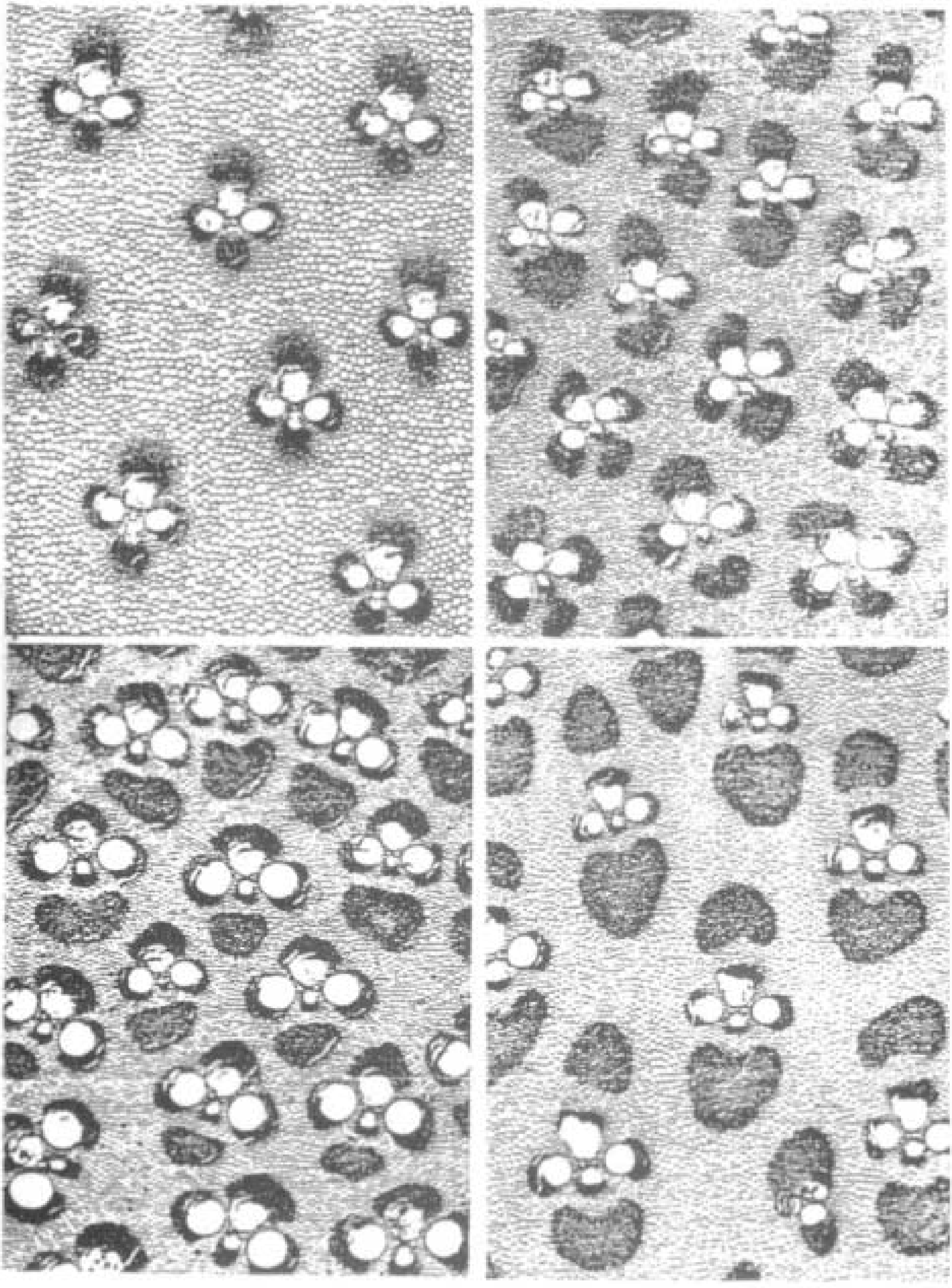

Figure 6. Different types of vascular bundles. I: Phyllostachys edulis. II Cephalostachyum pergracile. III Oxytonanthcra albociliata, IV: Thyrsostachys oliveri,

Of particular interest is also the presence of a protective layer in the parenchyma cells adjacent to metaxylem vessels; it consists of polysaccharides of the cellulose and hemicellulose type without lignification. This observation extends the presence of such a layer to monocots, besides dicots and softwoods.

Both the metaxylem vessels and the phloem tissue are surrounded by sclerenchyma sheaths. They differ considerably in size, shape and location according to their position in the culm and the bamboo species (Grosser and Liese, 1971; 1973; Wu and Wang, 1976; Jiang and Li, 1982).

Four to five major types of vascular bundles can be differentiated (cf. Fig. 6).

Type I : consisting ,of one central vascular strand; supporting tissue only as sclerenchyma sheaths;

Type II : consisting of one central vascular strand; supporting tissue only as sclerenchyma sheaths; sheath at the intercellular space (protoxylem) strikingly larger than the other three;

Type III : consisting-of two parts, the central vascular strand with sclerenchyma sheaths and one isolated fibre bundles;

Type IV : consisting of three parts, the central vascular strand with small sclerenchyma sheaths and two isolated fibre bundles outside and inside the central strand;

Type V : a semi-open type representing a further link in the evolution tendency _

The vascular bundle types and their distribution within the culm correlate with the taxonomic classification system of Holttum (1956) based on the ovary structure.

For example:

Type I alone : Arundinaria, *Phyllostachys, Fargeria, Sinanundinaria*

Type II alone : *Cephalostachyum, Pleioblastus*

Type II and III : Melocanna, *Schizostachyum*

Type III alone : *Oxytenanthera*

Type III and IV : *Bambusa, Dendrocalamus. Gigantochloa. Sinoclamus*

Leptomorph genera have only the vascular bundle type I, whereas pachymorph genera possess types II, III and IV. Size and shape of the vascular bundles vary across an internode but also with the height of a culm.

Fibres: The fibres constitute the sclerenchymatous tissue and occur in the internodes as caps of vascular bundles and in some species additionally as isolated strands. They contribute to 40 – 50% of the total culm tissue and 60 – 70% by weight. The fibres are long and tapered at their ends. The ratio of length to width varies between 150 : 1 and 250 : 1. The length shows considerable variation both between and within species.

Fibre measurements for 78 species were summarized by Liese and Grosser (1972). Generally, the fibers are much longer than those from hardwoods. Different values have been reported for one and the same species. The reason is mainly due to the considerable variation of fibre length within one culm. Across the culm wall the fibre length often increases from the periphery, reaches its maximum at about the middle and decreases towards the inner pan. However, few species show a general decrease from the outer part towards the center. The fibres in the inner part of the culm are always much shorter (20 – 40%).

An even greater variation of more than 100% exists longitudinally within one internode: the shortest fibres are always near to the nodes, the longest in the middle part (Fig. 7). With increasing height of the culm there

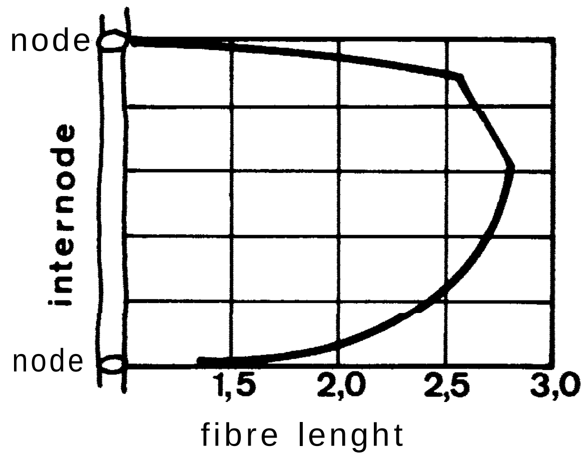

Figure 7. Variation of fibre length within *one, intemode.*

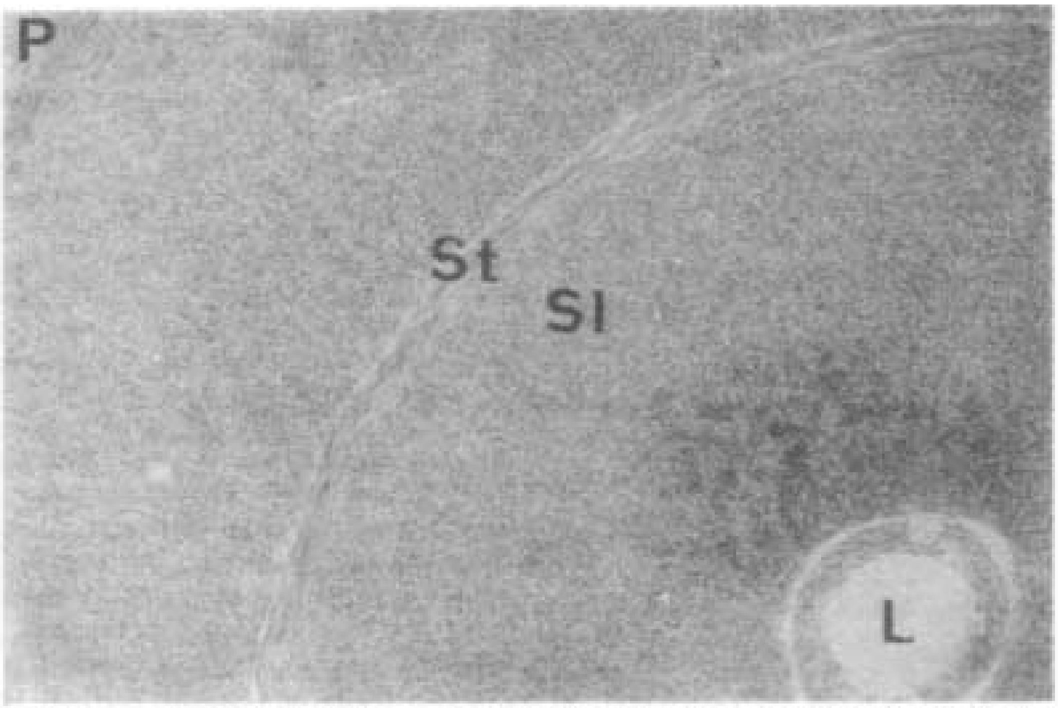

Figure 8. Crossection of delignified fibre wall with broad (s-1) and narrow (s-2) lamellae with different fibrillar orientation. P = Primary wall, L = Lumen, **Phyllostachys edulis**, *19.000 x.*

occurs only a slight reduction in fibre length. As the fibre length serves as an important criterion for pulping suitability, any measurement has to consider the distinct pattern of variation within the culm by taking representative samples.

The fibre length is positively and strongly correlated with fiber diameter, cell wall thickness and internode diameter, but not with lumen diameter and internode length. The fibre diameter varies between 11 and 19 urn, the lumen diameter between 2 – 4 um and the cell wall thickness between 4 -- 6 urn. The ultrastructure of most of the fibres is characterized by thick polylamellate secondary walls. This lamellation consists of alternating broad and narrow layers with differing fibrillar orientation (Fig. 8). In the broad lamellae the fibrils are oriented at a small angle to the fibre axis, whereas the narrow ones show mostly a transverse orientation 1 The narrow lamellae exhibit a higher lignin content than the broader ones. A typical tertiary wall is not present, but in some taxa (Oxytenanthera. *Bambusa, Ochlandra)* warts cover the innermost layer (Parameswaran and Liese, 1976; 1981) The polylamellate wall structure of the fibres especially at the periphery of the culm leads to an extremely high tensile strength, as demonstrated in engineering constructions with bamboo culms. Fig. 9 demonstrates

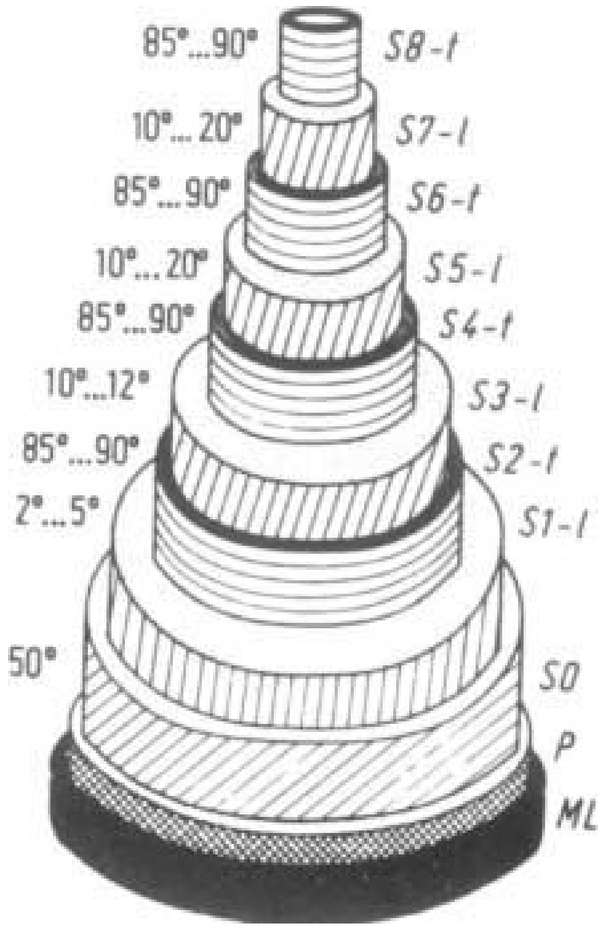

Figure 9. Model of the polylamellate structure of a thick waled bamboo fibre

the finestructural make-up of a bamboo fibre. The polylamellate structure does not exist in the cell'walls of fibres or tracheids of normal wood.

In culms with curved internodes no reaction tissue comparable with the tension wood-fibres of hardwoods has been observed, Some of the fibres with secondary walls possess septa in their lumina as in the case of hardwoods. The obvious difference is the presence of secondary thickening of the otherwise normally formed septum with a middle lamella-like layer and a primary wall. In the polylamellate fibres it is surprising to find septa containing several secondary wall lamellae, which are continued into the longitudinal wall of the fibres. These septa are lignified, a phenomenon normally absent in hardwood fibres.

Phloem: The phloem consists of large thin-walled sieve tubes, among which smaller companion cells are distributed. The fine structural studies have revealed the presence of plastids in sieve tubes characterized by osmiophilic cuneate proteinaceous bodies and lattice-like crystalloids with parallel tubular units. The plastids in sieve elements are devoid of starch. This type of plastid (P IIb) is characteristic of the Poaceae. Thus Bambusaceae belonging to the Poaceae of the Order Poales constitute yet another group with a definite plastid type, implying its taxonomic significance, as has been suggested for other families.

The density of the cytoplasm is caused by the presence of numerous ribosomes. At the periphery there occurs a rough endoplasmic reticulum, which is extensively developed. Mitochondria with well defined cristae are also present. Distinct, P-protein-like filament have not been observed at any stage. Dictyosomes are few. Occasionally, microbodies-like structures have been noticed with filamentous contents. The peripherally located nucleus is elongated and lobed. With the aging of the sieve elements there originates a vacuole in the centre of the cell, restricting the cytoplasm to the periphery. The plastids still contain well-developed cuneate proteinaceous bodies in addition to paracrystalline structures as well as vesicular and tubular units. The sieve elements are connected with each other by sieve pores which are lined with small callose platelets.

The wall of the sieve element is characterized by microfibrils oriented parallel to each other in a concentric manner around the cell and perpendicular to cell axis, creating a strong birefringence in the polarizing microscope. The sieve element wall contains generally only cellin material without obvious signs of lignification even in mature stages. Due to the prolonged and continuous growth of bamboo culms over more than 30 years it is conceivable that the sieve elements and metaxylem, vessels remain active in their transport function over several decades. Distributed among the sieve elements are companion cells, which are characterized by dense cytoplasm and a large nucleus. Mitochondria are numerous and the endoplasmic reticulum is extensively ramified. Plastids are few, The companion cells are connected with the sieve elements by plasmodesmata, which are branched on the companion cell side with a weak callose development.

Chemical Properties

Chemical constitution: The main constituents of the bamboo culms are cellulose, hemicellulose and lignin; minor constituents consist of resins, tannins, waxes and inorganic salts. The composition varies according to species, the conditions of growth, the age of the bamboo and the part of the culm. Because the bamboo culm tissue matures within a year when the soft and fragile sprout becomes hard and strong, the proportion of lignin and carbohydrates is changed during this period. However, after the full maturation of the culm, the chemical composition tends to remain rather constant. Tables 1, 2 give approximate chemical analysis for some bamboo species. Small differences exist along a culm, as shown in Table 2. The nodes contain less water-soluble extractives, pentosans, ash, and lignin but more cellulose than the internodes. The season influences the amount of water-soluble materials, which are higher in the dry season than in the rainy season. The starch content reaches its maximum in the driest months before the rainy season and sprouting. The ash content (1 – 5%) is higher in the inner part than in the outer one. The silica content varies on an average from 0.5 to 4%. increasing from bottom to top. Most silica is deposited in the epidermis, the

Table 1. Chemicalcompoadtion of some bamboo0(Tamolang et al.1980)

Species	H&cellulose (%)	Pentosans (%)	Lignin (%)	Akoholbenzene (%)	Hot water (%)	1 % NaOH (%)	Ash (%)	Silica (%)
Gigantochlca levis	62.9	18.8	24.2	3.2	4.4	28.3	5.3	2.8
Gigantochloa aspera	61.3	19.6	25.5	5.4	3.8	22.3	41	2.4
Bambusa vulgaris	66.5	21.1	26.9	4.1	5.1	27.9	2.4	1.5
Range of values for 10 Indian bamboo species	- 21.5	15. 1 32.2	22.0- 3.2	0.2- 6.9	3.4- 21.8	15.0- 3.2	1.7- 2.1	0.44
Range of values for 10 Japanese, Burmese and Indonesian bamboo species	61.9- 70.4	17.5- 22.7	19.8- 26.6	0.9- 10.8	5.3- 11.8	22.2. 29.8	0 8- 3.8	0 l- 1.7

Table 2. Chemical coniposition of Phyllostachyspubescens at different heights (Li 1983)

	Holocellulose (%)	Pentosans (%)	Lignin (%)	Ash (%)	alcoholbenzene (%)	Hot water extracts (%)	1% NaOH (%)
upper culm	54.1	31.8	24.7	1.2	6.0	7.0	25.6
middle culm	53.6	30.8	24.5	1.2	7.6	8.5	27.6
lower culm	54.4	32.9	24.0	1.1	7.4	9.3	28.3

"skin zone", whereas the nodes contain little silica and the tissues of the internodes almost none. Silica content affects the pulping properties of bamboo.

Cellulose and hemicellulose: The cellulose in bamboo amounts – as holocellulose – to more than 50% of the chemical constituents. As in other plants it consists of linear chains of 1, 4 bonded hydroglucose units (C2H1206). The number of glucose units in one molecular chain is referred to as the degree of polymerization (DP). The DP for bamboo is considerably higher than for dicotyledoneous woods. Cellulose is difficult to isolate in pure form because it is closely associated with the hemicelluloses and the lignin.

More than 90% of the bamboo hemicelluloses consist of a xylan which seems to be a 1, 4-linked linear polymer forming a 4-0-methyl-D-glucuronic acid, L-arabinose, and D-xylose in a molar ratio of 1 .0 : 1.3 : 25 respectively. It is in the main chain linear, but appears to be different from the xylan found in the woods of gymnosperms with regard to the degree of branching and molecular properties. Furthermore, the bamboo xylan contains 6 – 7% of native acetyl groups, which is a feature shared by hardwoods. With regard to the presence of arabinose it is closer to softwoods. Thus, the bamboo xylan is intermediate between hardwood and softwood xylans. These results indicate that the bamboo xylan has the unique structure of Gramineae (Higuchi, 1980).

Lignin: After cellulose, lignin represents the second most abundant constituent in the bamboo and much interest has been focused on its chemical nature and structure. Bamboo lignin is a typical grass lignin, which is built up from the three phenyl-propane units p-coumaryl, coniferyl, and sinapyl alcohols interconnected through biosynthetic pathways.

Bamboo grows very rapidly and completes the height growth within a few months reaching the full size. The growing bamboo shows various lignification stages from the bottom to the top portions of the same culm (Itoh and Shimaji, 1981). The lignification within every internode proceeds downward from top to bottom, whereas transversely it proceeds from inside to outside. During the height growth lignification of epidermaf cells and fibres precede that of ground tissue parenchyma. Full lignification of bamboo culm is completed within one growing season, showing no further ageing effects. No difference has been detected in lignin composition between vascular bundles and parenchyma tissue (Higuchi et al., 1966). Bamboo has been chosen as one of the suitable plants to study the biosynthesis of lignin. lnitially, these investigations were almost exclusively based on feeding experiments with radioactive precursors and it has been known that lignin is synthesized' from glucose formed by photosynthesis via the "Shikimic acid pathway" (Higuchi, 1969). Several key enzymes involved in the synthesis of shikimic acid were isolated from bamboo shoots (Fengel and Shao, 1984; 1985).

Physical and Mechanical Properties

Moisture content: The moisture content varies within one culm and is influenced by its age, the season of felling and the species, In the green stage greater differences exist within one culm as well as in relation to age, season and species. Young, one-year old shoots have a high relative moisture content of about 120 – 130% both at bottom and top. The nodes, however, show lower values than the internodes. These differences can amount to 25% of the water content and are larger at the base than at the top. In culms of 3 – 4 years the base has a higher moisture content than the top, e.g. for *Dendrocalamus strictus* about 100% and 60% relative moisture content respectively. The moisture content across the culm wall is higher in the inner part than in the outer part.

The season has a great influence on the water content of the culm, with a minimum at the end of the dry period, followed by a maximum in the rainy season, During this period the stem can double its water content. The variation due to the season is higher than the differences between base and top as well as between species. Among species the water content varies even in the same locality. This is mainly due to the variation in the amount of parenchyma cells, which corresponds to water holding capacity (Liese and Grover, 1961). The considerable differences in the moisture content of freshly felled culms have to be considered when determining the yield of bamboo expressed by its fresh weight.

Fibre saturation point and shrinkage: The fibre saturation point is influenced by the composition of the tissue and the amount of hygroscopic extractives. Since fibres and parenchyma have apparently a different fibre saturation point, their varying amount within a culm leads to different values. The fibre saturation point consequently differs within one culm and between species. For *Dendrocalamus strictus* the mean value was determined to be about 20%, for *Phyllostachys pubescens* about 13% (Ota, 1955) .

Unlike wood, bamboo begins to shrink right from the beginning of seasoning. The shrinkage affects both the thickness of the culm walls and the circumference. Seasoning of mature bamboo from green condition to about 20% moisture content leads to a shrinkage of 4 to 14% in the wall thickness and 3 to 12% in diameter. Bamboo tissue shrinks mainly in the radial direction, and the minimum deformation occurs in the axial direction. The tangential shrinkage is higher in the outer parts of the wall than in the inner parts. The shrinkage of the whole wall appears to be governed by the shrinkage of the outermost portion, which possesses also the highest specific gravity. Mature culms shrink less than immature ones.

Value of shrinkage from freshly felled to the oven-dry state were determined for *Phyllostachys pubescens* as follows: tangential: 8.2% for the outer part of the wall and 4.1% for the inner; radial: 6, 8% for the outer part and 7.2% for the inner; longitudinal: 0.17% for the outer part and 0.43% for the inner. Shrinkage starts simultaneously with the decrease of moisture content but does not continue regularly As water content diminishes from 70 to 40%, shrinkage stops; below this range it can again be initiated. Parenchyma tissue shrinks less in bamboo than in timber, while vascular fibres shrink as much as in timbers of the same specific gravity. When the moisture content is low, swelling due to absorption of water is almost equal to shrinkage. Moist heating leads to irreversible swelling in all directions. The percentage of swelling decreases with an increase of basic density (Kishen et al., 1958; Sekhar and Rawat, 1964).

Seasoning: The cut bamboo should first be dried for at least four weeks preferably standing upright. Lying horizontally almost doubles the drying time.

Air seasoning under cover is preferred, but seldom possible. Kiln seasoning under controlled conditions can be performed in about two to three weeks, but is considered to be uneconomical. The different seasoning behaviour of bamboo species is chiefly due to the different culm wall thickness which is the most important factor in controlling the rate of drying. The bottom part, therefore, takes much longer to season than the top portion. The rate of drying of immature cuims is generally faster than that of mature ones, but since the former have a higher moisture content they need longer. In the initial stages drying occurs quite rapidly, but slows down gradually as drying progresses.

Compared with timber of the same specific gravity, the drying period needed for air or kiln drying is longer due to the higher initial moisture content and the presence of water soluble extractives in the parenchyma cells. Their hygroscopicity in humid air is of about the same degree as invert sugar. The water absorption of dried bamboo therefore is quite rapid compared with that of timber. Bamboos, from which water-soluble extractives have been removed by soaking, dry faster and take up moisture slower than untreated ones.

Seasoning defects: Several defects can occur during seasoning. They may be due to the poor initial condition of the culm, due to excessive shrinkage during drying or both.

End splitting is not so common or severe as in timber. Surface cracking can occur during drying with all species. Cracks start at the nodes but their extent depends on the species and wall thickness. Thick-walled mature bamboo is especially liable to crack. A deformed surface of the round cross-section of immature bamboo is common. Thick-walled species evince an uneven outer surface, and cracks quite often develop on the inner side of the wall. Considerable shrinkage can take place in the middle part of the internodes, which become concave.

Collapse is a most serious seasoning defect. It occurs during artificial as well as natural drying processes and leads to cavities on the outer surface and to wide cracks on the inner part of the culm. Green bamboo is apt to collapse due to differential tension during drying. This shrinkage takes place in the early stages of seasoning. The outer fiber bundles are pressed together but the inner ones are stretched and this causes severe stresses. Immature bamboo is more liable to collapse than mature. Because of faster drying during the dry season, collapse occurs more often than during the rainy season. The lower portion with thicker walls is more liable to collapse than the upper portion. Slow drying bamboo species are apparently more liable to collapse than others.

To avoid seasoning defects, several methods of pretreatment have been tried. Soaking in water for two to six weeks did not improve the seasoning behaviour. Actually the devaluation due to checking, splitting and collapse was more severe in soaked pieces than in controls. Also water-soaked bamboo smells unpleasant, due to change of its organic constitutents. On the other hand, pieces which have been soaked are not liable to be attacked by powder post beetles during subsequent storage as the food material for the beetles leaches out during soaking.

Presteaming of green bamboo culms did not improve the seasoning as cracking and collapse still occur. Heat treatment over an open fire can be applied if the culms are half dry already, i.e. with not more than 50% moisture content.

Changes in colour can occur during seasoning. Fresh bamboo normally looks green or rather yellowish according to the stage of maturity, it changes during seasoning to a light green shade. Immature bamboos turn emerald green and mature ones pale yellow. Culms which are slowly air-dried develop a darker yellow colour than those which are dried rapidly in a kiln.

Specific gravity and mechanical properties: The specific gravity varies from about 0.5 to 0.8 (0.9) g/cm^3. The outer part of the culm has a far higher specific gravity than the inner part. The specific gravity increases along the culm from the bottom to the top. The mechanical properties are correlated with specific gravity. Bamboo possesses excellent mechanical properties. These depend mainly on the fiber content and therefore vary considerably within the culm and between species. At the base, for example, the bending strength of the outer part is 2 – 3 times that of the inner part. Such differences become smaller with increasing height of the culm. With the decreasing thickness of the culm wall there is an increase in specific gravity and mechanical strength of the inner parts which contain less parenchyma and more fibers, whereas these properties in the outer parts change only slightly. The variation of strength properties is much greater in the horizontal direction than in the vertical direction (Janssen, 1981),

A close correlation exists between specific gravity and maximum crushing strength. It seems that resistance to compression parallel to the grain is more or less uniform, hardly being affected by the height of the culm. For bending strength and modulus of elasticity, higher values were obtained from the upper part. Bamboo splints with the epidermis downwards have a higher fiber stress, bending strength and modulus of elasticity than those with the epidermis upwards. Splints without nodes have about one to two times the ultimate tensile strength of timbers such as spruce, pine, oak and beech.

The specific gravity of the nodes is generally higher .than that of the internodes due to less parenchyma, whereas bending strength, compression strength and shear strength are lower. This is due to the irregularity of the grain, caused by the arrangement of cells. The presence of nodes thus leads to a remarkable reduction in all strength properties.

Since there are still no standard methods of evaluating the strength properties of bamboo, as in the case of wood, the results are based on different methods of testing and on widely varying dimensions (Limaye, 1952; Sekhar and Bhartai, 1960).

The superior tensile strength of bamboo in relation to wood and steel is demonstrated by the following comparison: a steel bow of a certain quality (SA 37) of 1 cm^2 with 1 m length has a weight of 0.785 kg and a ultimate tensile force of ca. 40 kH; a stick from wood with the same length and weight would have a cross section of 13.5 cm^2 and a breaking point at 80 kN, but one from bamboo with 12 cm^2 would resist up to 240 kN; e.g. six times that of steel. The moisture content has a similar influence on the strength as it has in timber. Generally in the dry condition the strength is higher than in the green condition. This increase in strength with seasoning is more obvious for younger culms than for older ones. The differences between the air dry and green condition are sometimes relatively small, especially for bending and cleavage (cf. Table 3) (Ota, 1953).

Table 3. Mechanical properties of *Phyllostachys pubescens* in the water saturated, air dry and oven dry state (Suzuki 1950)

Property	Part		water saturated	air dry	oven dry
Bending strength N/mm^2	Outer		250	270	370
	inner		120	144	160
Cleavage strength N/mm^2	outer	6	7	8	
	inner	5	6	8	
	whole		6	7	8
Shear strength N/mm^2	whole		9	11	18
Janka-Hardness N/mm^2	outer	end	49	63	91
		side	22	25	37
	inner	end	27	32	66
		side	13	17	37

Influence Of Age

Age is an important factor for the development of strength properties. It is a general assumption that bamboos mature until about three years and have then reached their maximum strength. Investigations with Dendrocalamus strictus have shown that in the green condition older bamboo culms have higher strength properties than younger ones (the moisture content of the latter is much higher) In the dry condition, however, higher values were obtained at the age of one and two years than from older culms. Tests on splints from the central portion of the culm wall indicated better strength properties for one year old bamboo than for two years old ones, whereas those of culms of later years were slightly lower. Comprehensive tests by Zhou (1981) revealed a further increase of strength properties with age, viz for radial and tangential bending strength up to 8 years and for tensile strength and compression strength (parallel to the grain) up to 5 years. Older culms (10 years) showed a decrease in all strength properties.

Besides the above mentioned variations of properties within one culm, marked differences exist among individual culms from the same stand and even more among those from different localities. Needless to say. strength properties vary considerably between different species.

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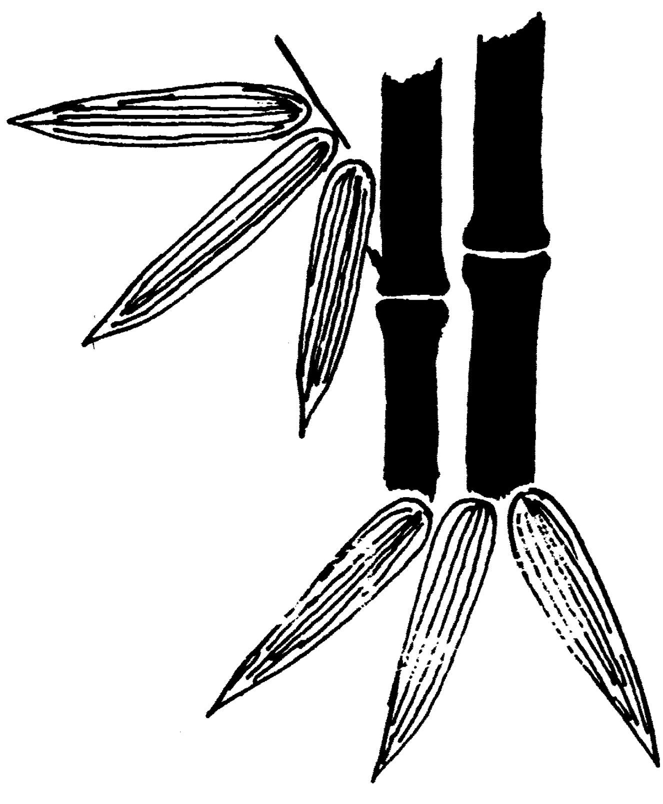

Anatomical Studies on Certain Bamboos Growing in Singapore

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Abstract

Bamboos are common useful plants in the Asian tropics mostly used by the rural people for food, housing and other utility purposes. Like other natural resources their production is decreasing and there is a renewed interest to promote their cultivation for economic benefits. The constraints are several including the basic information on plant growth, its structure and function. It is amazing to see so much paucity in our knowledge on bamboo anatomy. In this paper the anatomical details of the shoot apex, axillary buds, young and mature stems, culm and regular leaves and roots are presented. The need for further basic studies towards improving the plant growth and production is stressed.

Apart from individual scientific contributions, active teamwork is necessary to promote both research and manpower training in Asian countries. The latter is most important and urgent since there are very few in the field who are familiar with the taxonomy, growth and reproduction of bamboos. Multinational work programmes based on the model of certain on-going projects are suggested.

Introduction

The history of bamboos is inextricably interwoven with the history of man, especially in tropical countries. Most of the developing and poor countries are in the tropical zone and bamboo is a poor man's plant. The family Gramineae is one of the biggest among angiosperms with 450 genera and 4,500 species (Willis, 1951). Bamboos are classified into 21 genera and 170 species. In tropical Asia alone there are 14 genera and 120 species (Dransfield, 1980) Bamboos are the woody grasses that are comparatively less specialised than the herbaceous species in Gramineae. The taxonomy of Bambusoideae is based on spikelet structure (Gilliland, 1971) and among others, the limitations imposed by a) infrequent flowering of the various species, and b) lack of suitable fresh flowering materials for study are obvious. Hence, attempts are also made to use vegetative characters and here again the details are enumerated by very few observations on fresh materials and the emphasis is based on the morphology of culm leaves (Gilliland, 1971; Holttum, 1958). Although bamboos posses fairly conservative structures many variations are seen at subspecific or varietal levels. A detailed study especially in the field as well as on herbarium materials is necessary. For all practical purposes an illustrated simple guide to identify the useful bamboos would be of great practical value since biologists of various disciplines are interested in the propagation, genetic improvement and multiple use of bamboos.

The unique growth habit of bamboos and their fast growth rates provide an excellent opportunity to improve the biomass. This is very important to many of the poorer countries where forest resources are fast depleting and people are faced with many hardships caused by the lack of timber and fuel wood (Anon, 1980).

After the earlier work of Arber (1934), nothing much has been,done on the growth, structure, cytology and reproduction of bamboos. Nevertheless the general interest in bamboos continues among the biologists in general, and the foresters in particular. Their observations and reports are published from time to time (McClure, 1966). The first Symposium on Bamboos held in Singapore (sponsored by International Development Research Centre of Canada) and the publication of the proceedings therefrom is a significant contribution in this decade, updating the available information on bamboo research in Asia (Lessard and Chouinard, 1980). Most of the papers published are country or status reports emphasizing the need to increase bamboo production for economic gains. Some of the authors have clearly emphasized the urgent need for further basic research on bamboos that would help the conservation of genetic resources and the propagation of superior bamboos in great numbers employing both traditional and modern methods.

Due to a variety of reasons, the bamboos are difficult if not complex materials to work with and hence the paucity of knowledge on many basic aspects, including anatomy (Esau, 1965; 1977; Fahn,‘ 1967; Cutter, 1971). This paper is a brief report on certain anatomical characters of some wild and cultivated bamboo species present in Singapore.

Materials And Methods

Large mature clumps of bamboo species are growing wild in the nature reserves as well as the cultivated groups in Singapore Botanic Gardens. Certain species like Bambusa uerti-***cillate*** and other grass bamboos are also cultivated in private gardens. About six genera and 23 species are locally present (Table 1). The following eight species are presently investigated: Bambusa pergracile, B. teres, B. tulda, B. vulgaris, Gigantochloa oerticillata, Schizostachyum brachycladum, S. jaculans and Thyrsostachys siamensis. The materials were collected, photographed and the required parts were fixed in FAA. ButyI alcohol series was used for dehydration. The embedding of tissues, microtoming and staining were carried out following the standard methods (Sass, 1951).

Table 1. Bamboos growing in Singapore Botanic Gardens with Acquisition Numbers.

1. Bambusa dolichoclada. W. 260B.
2. *B. glaucescens. W. 247.*
3. B. pergracile. W. 253.
4. B. teres’ W. 252.
5. B. tulda’ W. 233.
6. B. variegata. W. 271.
7. B. ventricosa. W. 232, W. 264A, W. 269, W. 275.
8. *B. vulgaris’* W. 243A, A. 260A, Y 95, Y 95A.
9. Dendrocalamus pendulus. W. 280.
10. Gigantochloa apus. W. 254, W 277A, W 302.
11. G. naname. W. 278.
12. G. verticillata’ W. 256B.
13. Phyllostachys sp. W. 248, W. 249.
14. Schizostachys brachycladum’ W. 231. W. 268, W. 277.
15. S. jaculans* W. 154, W. 243.
16. Thyrsostachys *siamensis’* W. 215, W. 222, W. 237, W. 262, W. 277.
17. Bambusa arundinacea.
18. B. heterostachya.
19. B. ridleyi.
20. B. oerticillata.
21. *Dendrocalamus strictus*
22. *Gigan* tochloa *levis*.
23. G. ridleyi.

• Used in the present study; easily accessible and ideally situated for growth studies. 17-23. less commonly found due to urbanisation.

Observations

Morphological considerations: Both taxonomic and general descriptions are available for the species mentioned in Table 1, and many of them are commercially important species (Gilliland, 1971; Holttum, 1958) Hence, these details are not repeated again. The healthy mature clumps of bamboos grown in Singapore Botanic-Gardens are easily accessible to study the growth characteristics. Due to the humid tropical climate the growth, in general, is non-seasonal and new shoots are produced all the year round. In some species the growth is more profuse in the post monsoon period of February-April. The fresh bamboo shoots are of varied sizes and shapes, all covered with compactly arranged culm sheaths (Figs. l-8). The culm sheaths vary in size and shape depending on the species examined (Figs. 'A-C). The elongation of the axis or the culm commences when the shoots are approximately 2-3 feet long, and the cone-shaped structure becomes axial with distinct nodes and internodes. The culm sheaths are placed distant apart due to internodal elongation and they fall off after 120-160 days after the internode elongation begins. How long the bamboo shoots would take, in terms of days or weeks, to emerge out of the soil surface and grow further into culms is yet to be determined. The bamboo clumps studied presently are more than 30-50 years old according to the records maintained in the Gardens. Although most of the bamboo species grow in clumps there are certain variations among them. Some of the clumps are very dense due to heavy accumulation of debris, soil and rhizomes. Size, colour, length of internodes and formation of aerial branches are all variable. The basal part of the clump in certain species like B. pergracile, B. vulgaris is very woody, dense and form thick rhizome plexus which appears as a raised platform of 2-4 feet above ground and the dense culms emerge out of the thicket. In other species the beginning of each culm can be seen separately. The size, colour and the thickness of the growing axes vary among these different species (Figs. A, B, l-4). Some of the axillary buds at the mature nodes grow to form the lateral branches at the base of which many roots are formed. The number of young shoots formed from each bud is variable. Unlike the culm sheaths, which are variable in shape and size, the lamina of the regular leaves are less distinctive at the species level. They are all dorsiventral structures and their sizes vary in different species (Figs. l-8). Both axillary as well as accessory structures are common and the latter are more profuse at the lower nodes developing into roots. Some of the axillary buds at higher nodes develop into lateral branches.

Shoot apices: The origin and development of shoots in woody monocots is unique in many respects. The apices in most of them are conical (Fig. D, l-6). The apex of B. vulgaris is comparatively broader than others (Fig. D, 3). The developing leaf primordia are arranged more or less at the same transverse level, protecting the shoot apex and contributing to the formation of abroad massive structure (Fig. D, 3). In all of them the developing leaves grow vertically and parallel to the axis and cover the apex. The photographs in Fig. D, 1-6 are the general view of the apices taken at lower magnification showing apex, developing leaves and their arrangement as well as the gradual distinction seen in the formation of nodes and internodes. The closer view of the shoot apices are shown in Fig. E, l-8. The tissue organization in them conforms to the generalized angiosperm pattern with regular tunica, corpus, peripheral and rib meristems (Fig. E, 1, 3, 5, 7). The tunica consists of two well defined cell layers and they are distinctly seen in all the species investigated (Fig. E, 2, 4, 6, 8). The corpus zone is about six to ten layers deep below the inner layer of the tunica with many darkly stained, isodiametric cells. The nuclei are large compared to cell size and contents. The tissue below the corpus is highly meristematic. Active growth of this region results in the formation of more tissue towards the establishment of the stem axis (Fig. E, 2, 4, 6, 8). The corpus zone extends into the rib meristem below and laterally into the peripheral meristem, the tissues of which are actively dividing and densely stained (Fig. E, 1, 3, 5, 7). Very many prominent vascular strands are also present. The rib meristem basal to the corpus differentiates into a very distinct intercalary merisrem with many meristematic cell layers. The derivatives of these layers are added on basipetally which enlarge and in sections the central part of the apex appears lighter in colour (Fig. E, 1, 3, 5, 7).

Figure A. 1-4. 1. *Bambusa pergracile.* 2. *B. vulgaris.* 3. *Schizostachyum brachicladum.* 4. *B. tulda.* Part of aerial shoots with regular photosynthetic leaves, culm shoots enveloped by culm sheaths are shown in each. At emergence culm shoots are conical in outline and later become axial structures as shown in 2 and 3.

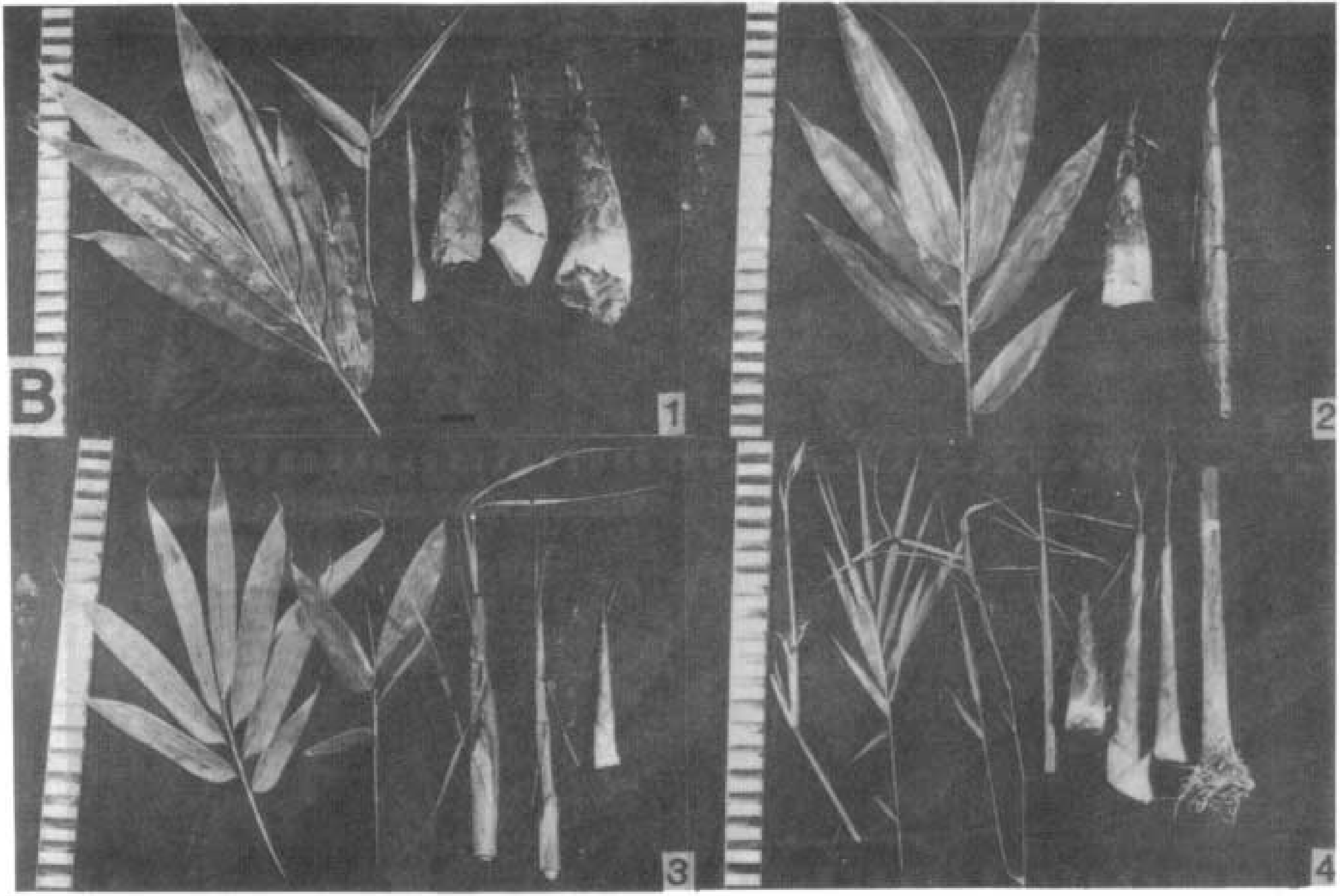
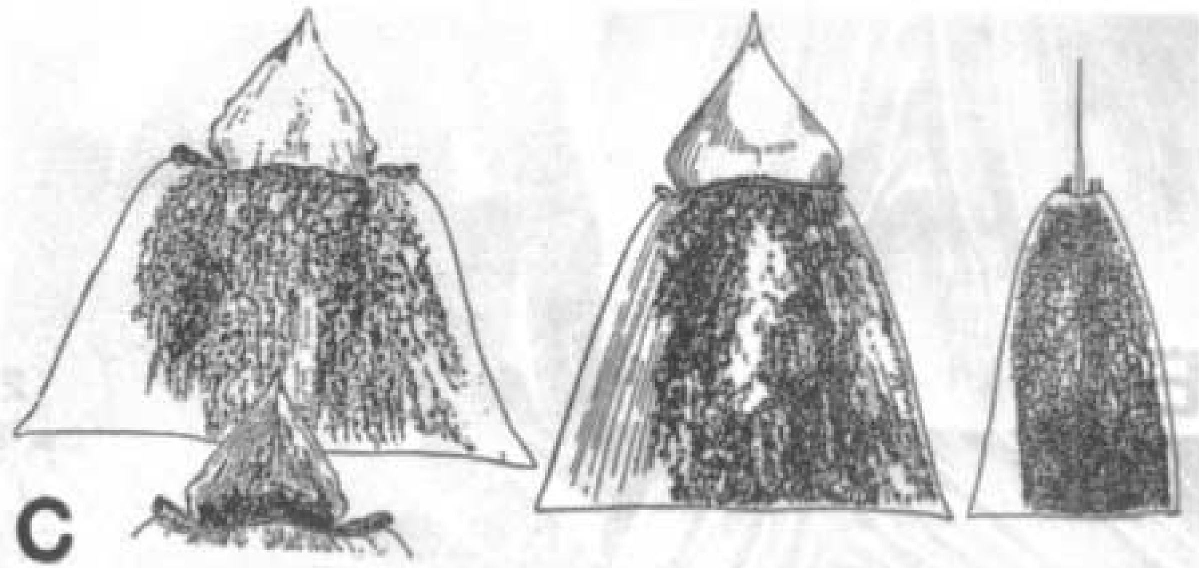


Figure B. 1-4. 1. *B. teres.* 2. *Gigantochloa verticillata.* 3. *Schizostachyum jaculans.* 4. *Thyrsostachys siamensis.* Descriptions are same as in Figure A.



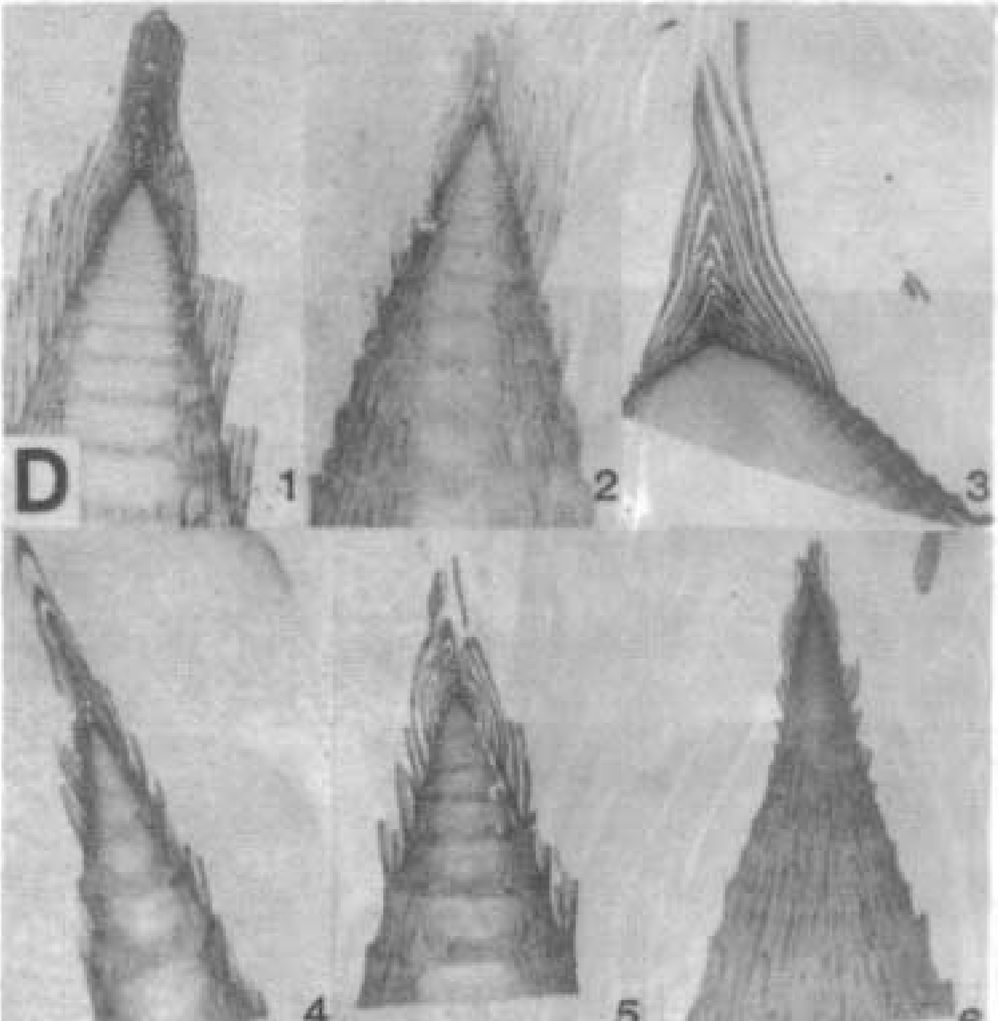


Figure C, 1-3. 1. *B. vulgaris*. 2. *Schizostachyum brachycladum*. 3. *S. jaculans*. Culm sheaths enlarged to show the broad base and upper triangular area. In 1, the tip of the next leaf is overlapping. In 3, the upper part is needle-like.

Figure D, 1-6. Enlarged view shoot apices as seen under dissecting microscope. 1. *B. pergracile*. 2. *B. teres*. 3. *B. vulgaris*. 4. *Gigantochloa verticillata*. 5. *Schizostachyum jaculans*. 6. *Thyrsostachys siamensis*. Note the broad apex in 3 and all the rest are typically conical. Nodal and internodal regions very distinct in 1, 2, 4, 5, slightly distinct in 3 and not very distinct in 6. Note the large number of procambial strands in 6.

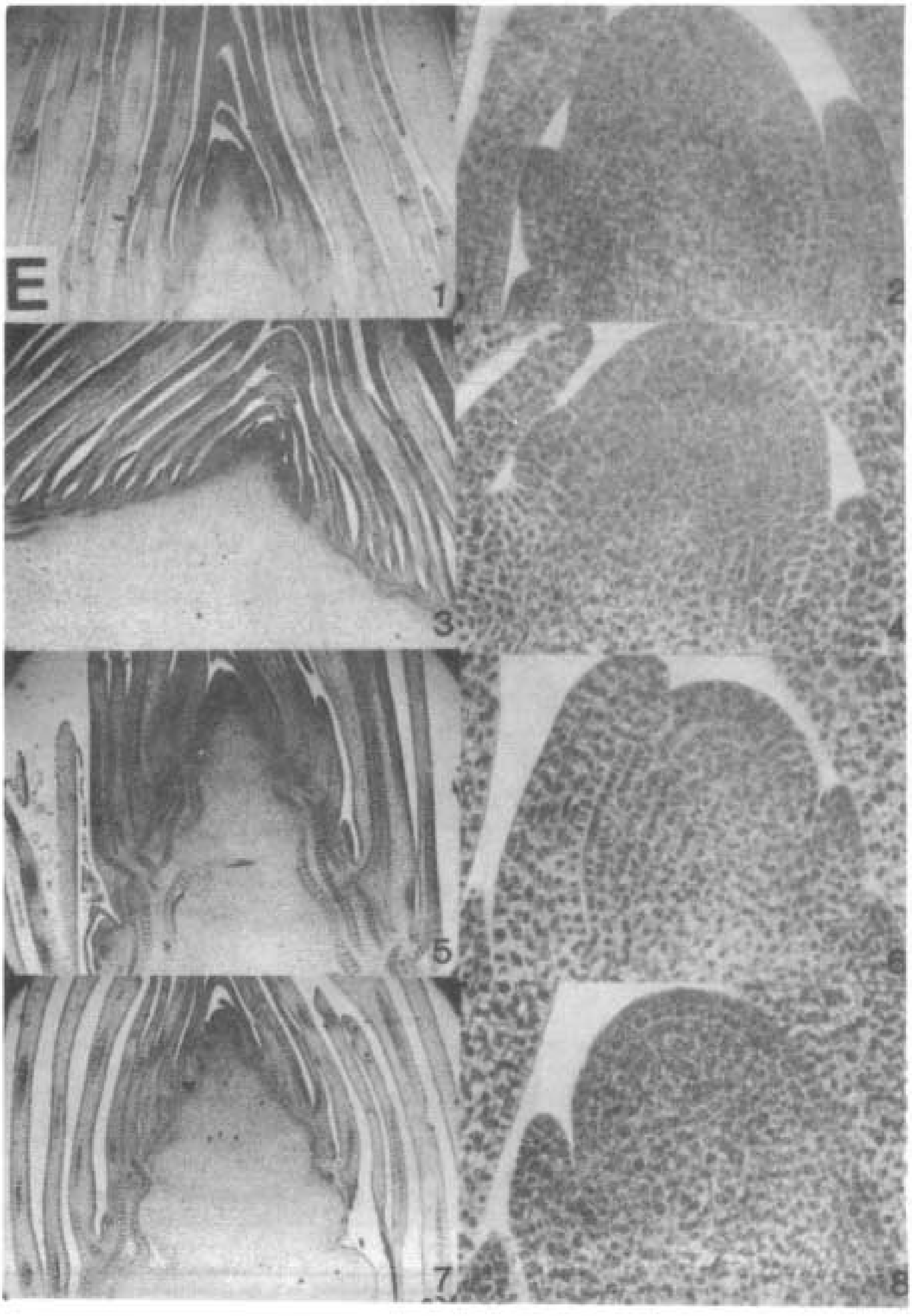


Figure E. 1-8. Photomicrographs of shoot apices. 1, 2. *B. teres.* 3, 4. *B. vulgaris.* 5, 6. *Gigantochloa verticillata.* 7, 8. *Schizostachyum jaculans.* The pictures on left show the whole apices with dome-shaped apex, several leaf primordia with or without axillary buds. The pictures on right are the enlargements of those on left showing two-layered tunica, corpus, rib meristem and the developing leaf primordia.

The leaf primordia develop at the flank of the shoot apex and most of them form the leaf sheaths (Fig. E, 1, 3, 5, 7). Many of them have a bigger or thicker base and the terminal part ends as an attenuated structure. Majority of the primordia have a knick or depression in the middle and others split in the middle or at the base (Fig. E, 1, 5, 7). The bamboo shoots are covered by a variety of sheath-like structures that encircle the stem. The various primordia develop into culm sheaths, sheath blades, ligules and other outgrowths on the iigules. Thus the apex as a whole is a centre of immense activity producing a large number of primordia that differentiate into many varied structures subsequently (Fig. E, 1,3,5,7).

From about the level of eighth to tenth node the demarcation between nodal and internodal regions becomes distinct. The nodal plates appear as dark cross bars separating the lightly colaured internodal regions (Figs. D, E). The intercalary meristem at two nodes are enlarged (Fig. G, 8, 9). In the former, the files of actively dividing cells are very clear and neatly arranged. In the latter, which is an older node the nodal plate has become thicker with vascular strands traversing in different directions. The intercaiary meristem is intact both below and above the nodal plates. The disintegration of cells making way for the hollow cavity is also in progress (Fig. G. 9).

Axillary buds: The bud primordia are distinct and they can be distinguished from the leaf primordia even during early stages of development. The latter develop as elongated, slender structures growing acropetally over-arching the main apex. in contrast the primordia of the axillary buds are asymmetrical in outline since the growth is more towards the leaf than on the stem side. Buds in different stages of development are shown in Fig. F, 1-6. Because of their sloping position the first prophyli formed towards the axis is shorter, somewhat triangular in outline and grows parallel to the stem axis and the second prophyll is longer, over-arches the apex and joins the triangular structure. Both of them cover the developing apex (Fig. F, 5, 6). The middle part of the bud enlarges and the subsequent leaf primordia originate as lateral structures. The apical region outgrows the primordia and develops into a broad dome shaped apex. The apex of the axillary bud also shows a two-layered tunica and a regular corpus region. The leaf primordia remain small and more than six to eight prophylis are present in certain buds. The first two prophylis formed would cover the bud for a long time and these are well vascularised (Fig. F, 6, 7). The subtending axial tissue below the bud undergoes a series of periclinal divisions and many curved layers of meristematic tissue are present organising the shell zone (Fig. F, 6). There is considerable variation in bud development among the different species studied. In B. teres and B. *vulgaris,* no bud initiation is seen even up to 10- 12 leaf stage. They seem to develop much later (Fig. F, 1, 2). In others, such as G. *verticillata,* *S. jaculans,* *T. siamensis* and B. teres the bud primordia develop much earlier (Fig. E, 1, 5, 7). More number of apices cut both transversely and longitudinally need to be examined to determine the early or late bud development and their relative positions to one another. This is very important to correlate the rate of shoot growth and the influence of bud dominance in branching.

Structure of bamboo shoots: The conical bamboo shoots were studied in detail (Figs. A, B, l-4). The young axis is surrounded by a number of culm sheaths and when these are removed one by one the young stem is exposed. In B. pergracile, B. *vulgaris B. tulda* and B. teres the conical shoots are relatively massive when compared with other species (Figs. A, B, l-4). The central cylindrical stem is relatively soft and easy to section. The various regions of the stem axis were studied a) from the periphery to the centre and b) from the tip to the base.

The cortical region shows a single layered epidermis and the surface is usually covered with many epidermal hairs (Fig. G, 1, 2, 4). About two to three subepidermal layers also consist of small cell layers followed by the ground tissue in which the numerous vascular bundles of different sizes showing varying stages of development are present (Fig. G, 2-5). In some, only groups of fiber cells are present with one, two or few vascular elements. Judged by the configuration and structure, it is clear that fiber cells develop early and there is no synchronisation in development either between the vascular and non-vascular elements or between the xylem and phloem tissues. Also the peripheral bundles of similar sizes show varied number or quantity of xylem and phloem tissues. In contrast, the

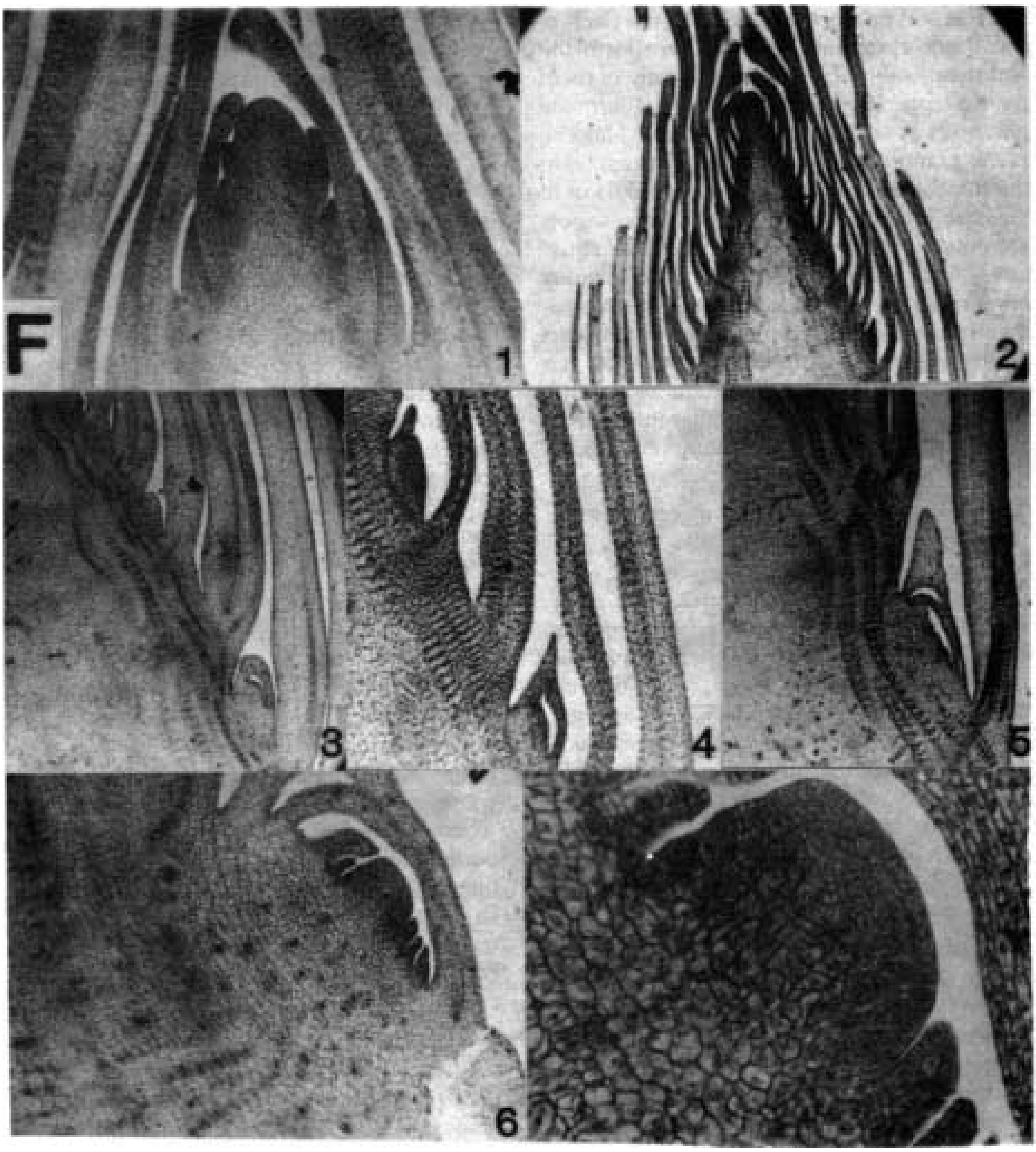


Figure F, 1-7. 1. LS. shoot apex B, teres showing development of leaf primordia. 2. L.S. shoot spex Thyrsostachys siamensis. Note the elongated apex with many leaf primordia and a single axillary bud on right hand side of the axis. 3. 7. L.S. apex of B. teres showing the development of axillary buds. The early prophylls arch over the apex and central part of the bud enlarges. well protected. The central dome and prophylls are well developed as seen in 6 and 7. Two-layered tunica and corpus are very clear in 7.

bundles in the centre are fairly uniform in size and contents (Fig. G, 6). Both proto and metaxylem as well as phloem can be easily distinguished. The sclerenchymatous caps seem to develop later. In general, it is clear that the vascular bundle development is centrifugal. In B. teres there are many radial vascular strands extending from the periphery to the cortex (Fig. 6). Since tissues for sectioning were taken at random from the different regions of the cone, no generalization can be made on the sequential development of vascular strands with regard to their relationship to the main apex or the nodes. It is possible to establish the relative degree of tissue maturity in the massive, conical bamboo

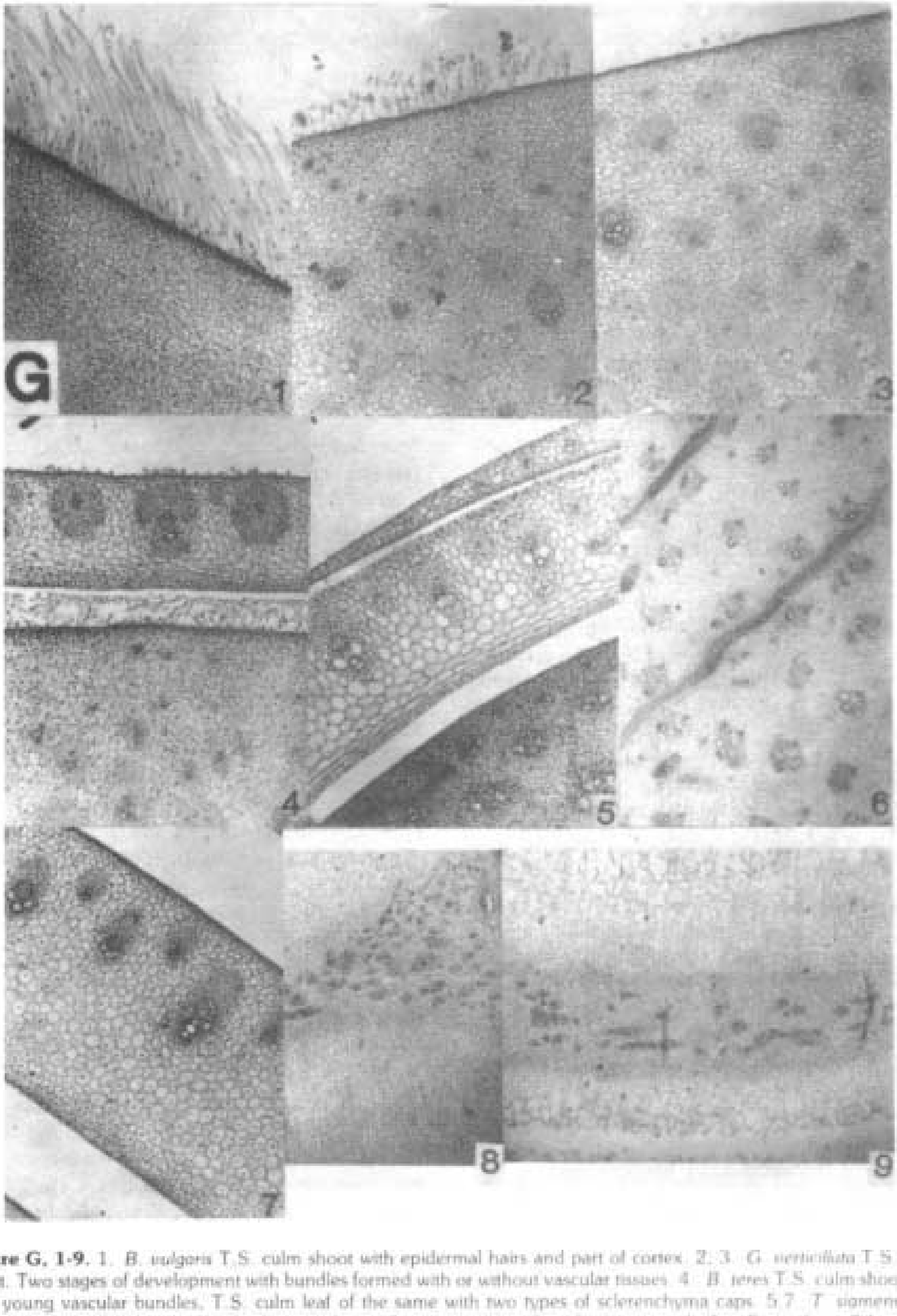


Figure G, 1-9. 1. *B. vulgaris* T.S. culm shoot with epidermal hairs and part of cortex. 2, 3. *G. verticillata* T.S. culm shoot. Two stages of development with bundles formed with or without vascular tissues. 4. *B. teres* T.S. culm shoot with very young vascular bundles, T.S. culm leaf of the same with two types of sclerenchyma caps. 5-7. *T. siamensis*. 5, 6. T.S. young culm shoot, peripheral part and central parts, respectively with many vascular bundles and parallel vascular strands extending radially. 7. T.S. culm leaf. Note the organisation of vascular bundles and mesophyll. Note the similarity in all of them with regard to undifferentiated mesophyll and vascular bundles towards the upper epidermis. The size and shape of sclerenchyma caps differ from one another. 8, 9. *S. jaculans*. Internodal portions enlarged to show the intercalary meristems, in 8 the meristem is intact and in 9, the cell layers above and below the nodal plate are degenerating making way for the pith cavity. The peripheral and central part of the nodal plates are enlarged respectively in these two figures.

shoots with reference to the enlargement of the axis and the nodal positions. Similarly, a correlation can also be established between the vascular bundles that are present in the outer and inner cortical regions.

Culm sheath: The bases of culm sheaths are cut along with the tender main axis (Fig. G, 4, 5, 7). The transections of these show distinct structural variations between their outer and inner surfaces. As in the stem the outer epidermis consists of a single layer of cells with or without epidermal outgrowths. One or two subepidermal layers differentiate into sclerenchyma. The rest of the mesophyll is undifferentiated and the cells increase in their size towards the inner epidermis. The vascular bundles are of different sizes and shapes either oval or round (Fig. G, 4, 5, 7) covered all round or partly by prominent sclerenchymatous bundle caps. In the early stages of development, the vascular bundles occupy almost or more than half of the cross sectional area of the sheath. With subsequent development of the mesophyll, more towards the inner epidermis, the vascular bundles are restricted more towards the outer epidermis (Fig. G, 5, 7). The inner epidermis is small, one-layered, distinctive with thickwalled cells. Facing the bigger bundles there is a group of smaller cells with characteristic thick walls resembling collenchyma. Many of the enlarged mesophyll cells in T. *siamensis* had two or more nuclei in them (Fig. G, 7).

Stem structure: The aerial stems of the different species studied show the monocot type of stem anatomy with a distinct epidermal layer, ground tissue and big vascular bundles (Figs. H, 2, 6, 8; I, 1, 3). In S. *jaculans* the epidermis is more prominent than in others- with enlarged cells, with three to four layers of smaller subepidermal cells that develop later into regular sclerenchyma (Fig. H, 8). in other species, the subepidermal scierenchyma is formed early (Figs. H. 2, 6; I, 3). The ground parenchyma is homogeneous in nature with cell size increasing centrifugally. Additional enlarged cell groups surrounding the vascular bundles are distinct in certain species like S. jaculans and *B. pergracile* (Fig. H, 1, 8, 9) These cell layers may develop into thick sclerenchyma at subsequent stages. The smaller bundles are arranged nearer the periphery and the larger bundles are towards the centre. The vascular bundles are collateral with sclerenchyma sheaths or caps present either in two or three groups.

In most of the cases, only young stems are used and obviously the distinct fiber strands or caps are yet to develop. The pith cavity formation is distinct in *B. vulgaris*, *S. jaculans* and T. siamensis (Figs. H, 6; I, 1, 2). The stem structure of B. teres is shown in detail with both the peripheral and central part of the axis with intact perenchyma (Fig. H, Z-5). Within the central part there are two distinct vascular bundles, slightly smaller in size than those present in the inner peripheral region. The arrangement of the vascular tissues in these two medullary bundles is similar to those in the peripheral region. The demarcation between the peripheral and central regions is also clear (Fig. H, 3). Another very interesting detail is that most of the enlarged pith cells have two or more nuclei in them (Fig: H, 4, 5). In B. *vulgaris* the innermost cell layers adjacent to pith are somewhat thick-walled and very distinct almost appearing as a border zone (Fig. H, 6).

Root structure: As seen in transverse sections, the young roots show a number of epidermal hairs, fairly straight and majority of them are uninucleate (Fig. l, 5). Below the epidermis there are. three to four layers of sclerenchyma followed by a uniform region of parenchyma. The stelar structure is typically monocotyledonous with regular endodermis and distinct vascular groups of xylem and phloem. Many large air spaces are present both in cortex and the stelar regions which seem to be a common feature in many grasses. In the older roots the hairs are slightly thicker and many of them have small kinks and curved outlines. In a few cases even the branching of root hairs is seen (Fig. I, 6, 7).

Root hairs are simple epidermal outgrowths, commonly formed on young roots, showing very few or no abnormalities in their cell morphology. Very few cases are known where the root hairs are actually branched (Rao and Chin, 1972). Such details are discussed mostly in relation to certain dicots and this seems to be the first instance for monocots and especially the bamboos (Rao and Chin, 1972).

The structure of rhizome and root system is important since they are adaptable to a variety of soil conditions and prevent soil erosion. In many ways they are much more

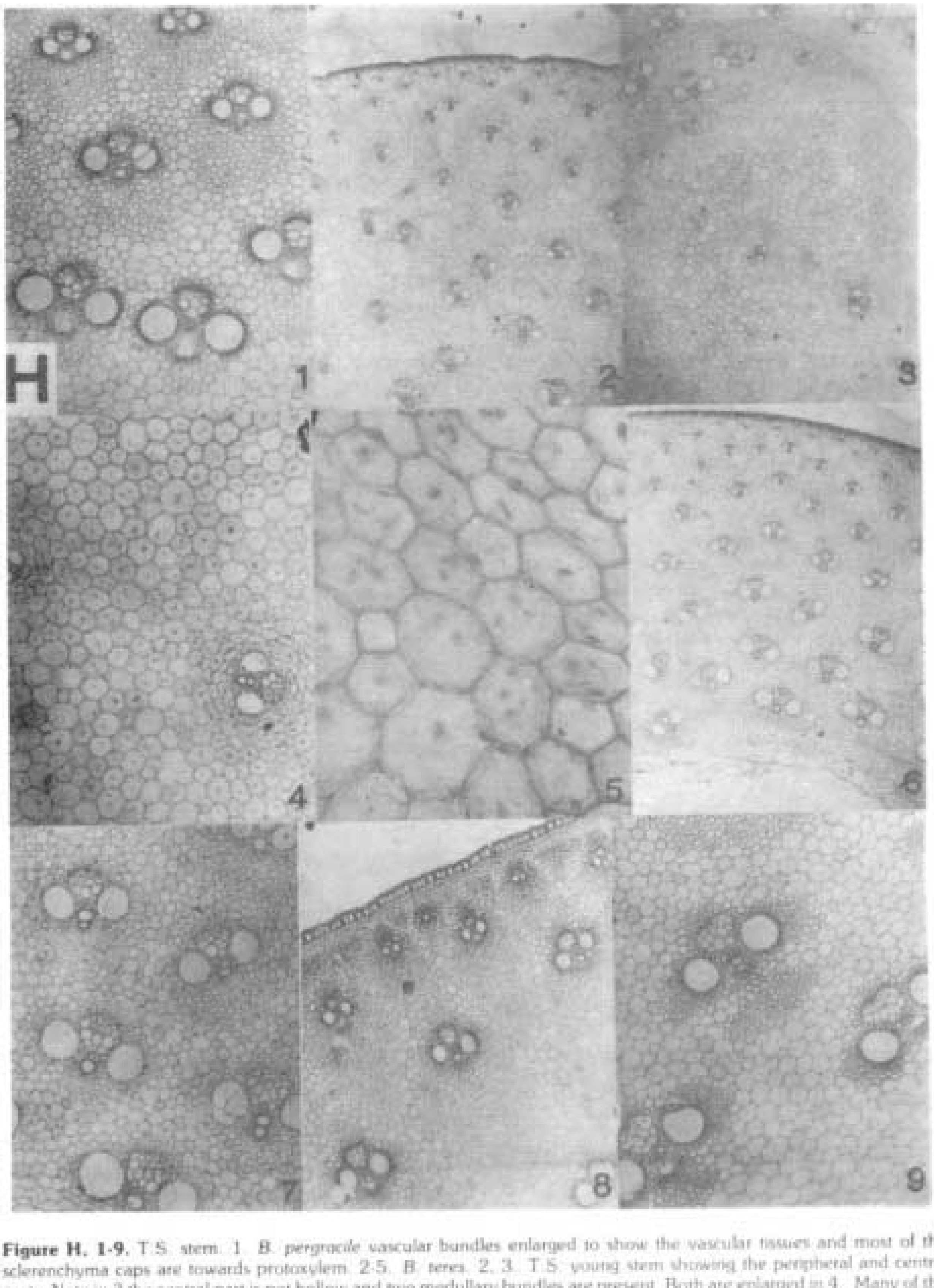


Figure H, 1-9. T.S. stem. 1. *B. pergracile* vascular bundles enlarged to show the vascular tissues and most of the sclerenchyma caps are towards protoxylem. 2-5. *B. teres*. 2, 3. T.S. young stem showing the peripheral and central parts. Note in 3 the central part is not hollow and two medullary bundles are present. Both are enlarged in 4. Many of the cells in the medullary part show two, three or more nuclei in them. 6, 7. *B. vulgaris* T.S. whole stem in 6 shows variations in size of the bundles from peripheral to central regions; note the increase in size of the bundles. Pith cavity in centre and adjacent to pith region there are three to four distinct cell layers. Bundles of the same enlarged. Vascular tissue well developed and sclerenchyma yet to be formed. 8, 9. *S. jaculans*. Part of stem showing epidermis and the adjacent regions with gradual increase in size of vascular bundles. Vascular bundles enlarged in 9, where the vascular tissues are clearly seen with three groups of sclerenchyma.

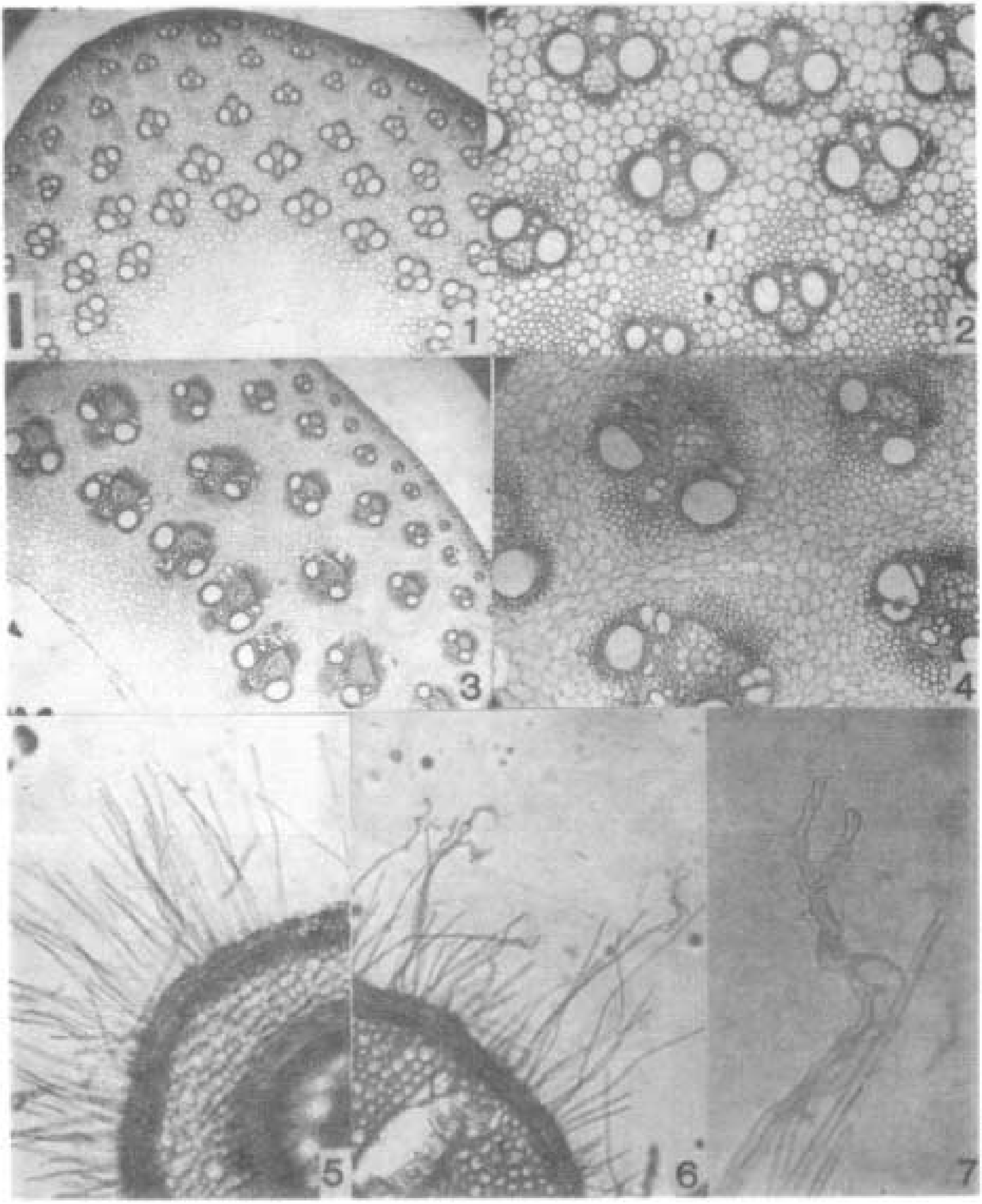


Figure I, 1-7. T.S. stems and roots. 1, 2. *B. tulda*. Bundles arranged in five or six rings. Sclerenchyma caps developed in some. 3, 4. *S. brachycladum*. Bundles in five rings. Sclerenchyma more well developed on phloem side than on xylem. 5, 6. *B. verticillata*. Root hairs on younq and fairly old roots, straight on the former and somewhat crooked and twisted on the latter. 7. shows a branched root hair with many kinks.

efficient than the grasses which are the early colonisers of the cleared or open land.

Leaf structure: Leaves in the family Gramineae are specialised structures. Many of them are primarily the protective structures covering the growing parts of the rhizome, shoot apices and axillary buds. The rhizome sheaths are simple, triangular in outline with small pointed ends and near the apex the margin is sometimes serrated. The structure that covers the bamboo shoots and young stems are the culm sheaths which have smooth, adaxial and rough abaxial surfaces, the latter surface covered with many types of epidermal outgrowths including hairs (Fig. C, l-3). The culm sheath is also triangular in outline and the basal part is broad with a narrow terminal part (Fig. C, l-3). Distinct Iigule and auricles may be present at the point where the broad base slightly narrows down to form the triangular structure (Fig. G, 9-l 1). The third structure is the foliage leaf with the basal sheath or a petiole and a regular lamina.

The transections of the lamina in different species reveal an upper epidermis, two or three layers of mesophyll with or without a distinct palisade layer, fairly large air spaces, lower mesophyll and lower epidermis (Fig. J, 1-13). The upper epidermal layer is more distinctive than the lower with groups of bulliform cells which are bigger in certain species than in others (Fig. J, 4. 5, 8. 10. 12). The groups of bulliform cells alternate with air spaces. The cuticle is thick on both the layers and in many of them like B. teres, B. *tulda,* B. vulgaris and G. *verticillata* the cuticle on lower epidermis is papillate (Fig. J, 3, 5, 8). In S. *brachycladum* the palisade layer is much more prominent. The plicate or lobed condition is common in many of the outer mesophyll layers. At places where either air spaces or the bulliform cells are present the upper palisade is restricted to a single layer. The second layer is represented by a group of two or four cells that form a bridge interconnecting the upper mesophyll with the lower. The size and extent of air spaces are also variable (Fig. J. 1. 2. 4. 6, 7. 9, 11. 13). In B. tulda, G. verticillata and S. jaculans the prominent intercostal ridges are occasionally present and these form regular hump-like structures and each one of these consists well developed sclerenchymatbus tissue (Fig. J. 9. 11). Both the number and the size of bulliform cells increase between these groups of sclerenchymatous humps. The vascular bundles in the leaves show the regular monocotyledonous structure and a group of sclerenchymatous cells interconnect the vascular bundles with upper and lower epidermis (Fig. J, 3, 10, 12). Stomata are commonly present on the lower epidermis and in leaf transections the guard cells appear smaller than the epidermal cells and devoid of papillate outgrowths or thick cuticle (Fig. J, 3, 5, 12).

Discussion

The well known work on bamboos by McClure (1966) summarises the basic work done until 1960s. A critical survey of literature. however reveals the fact that by and large the basic botany of bamboos is yet to- be worked out and recorded in a proper manner. The literature available at present is fragmentary, scattered and inadequate and the reasons are not too difficult to understand. Like in other aspects of tropical plants. whether wild or cultivated, there is very little effort made to study them well by the local scientists. Lack of trained manpower is another problem. Only taxonomic studies are fairly complete and here again, there is no well illustrated simple guide, easy to use by the common man or others not familiar with technical terms.

More specifically, as it refers to the present study, it was very revealing to note that there is hardly any good paper describing the anatomy of bamboos. The list of references given by McClure (1966) and in the proceedings of the last workshop on bamboos in Asia would substantiate the above statement. Standard recent reference works on plant anatomy (Esau. 1977; Fahn. 1967; Cutter. 1971) or even some of the older works (Goebel. 1930; Eames and McDaniels. 1947; Eames. 1961) do not provide much information due to the lack of any anatomical research. The recent papers published by other Asian or German botanists are not easily available since they are in local journals. As stated before. bamboo anatomy is hard to work since most of the structures provide a good challenge to microtomy and the structures are relatively difficult to interpret. even though many other grasses including the various cereal crops are fairly well studied. Another reason for this inade-

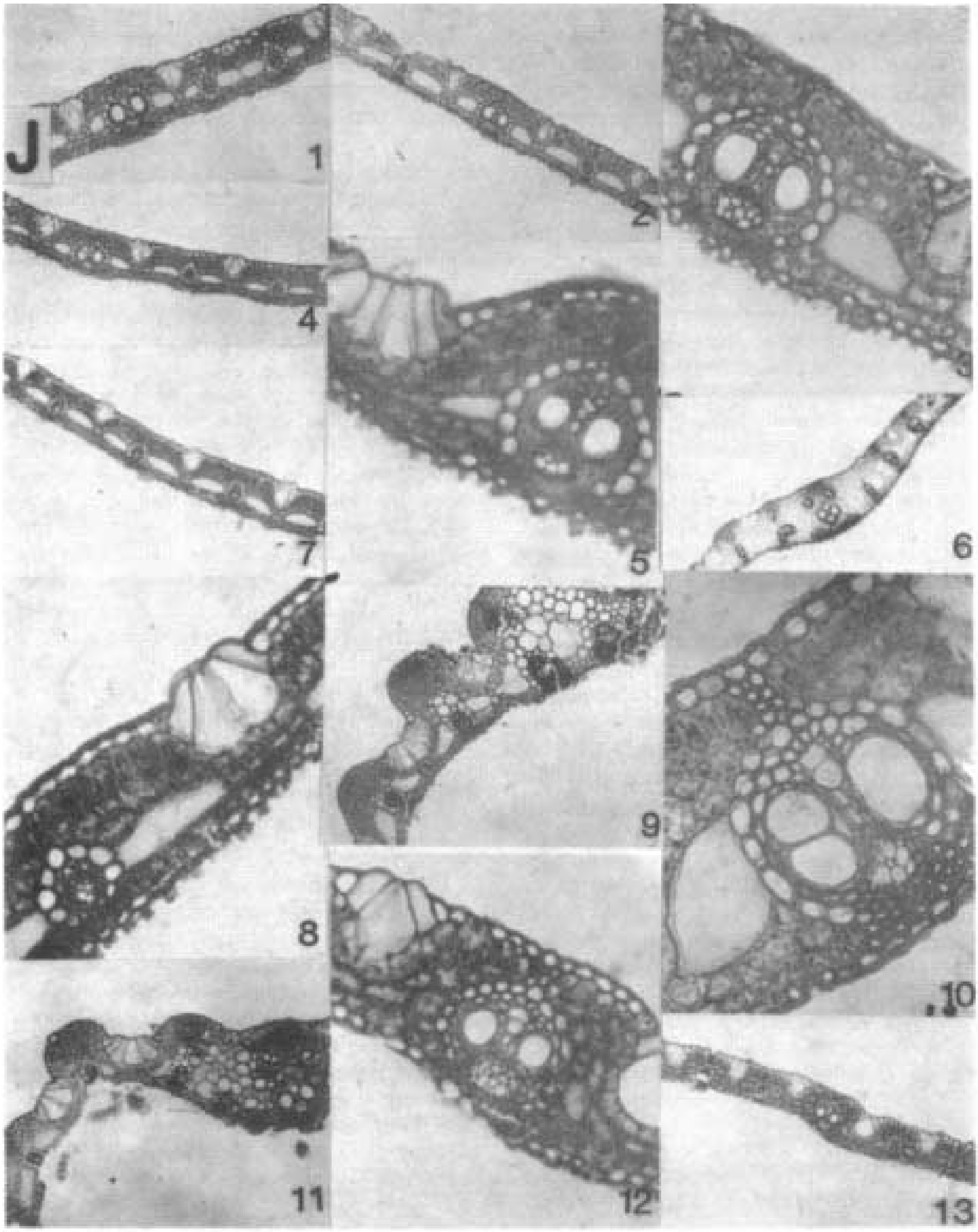


Figure J, X-13. Leaf transections as seen under low and high magnifications. 1. B pergracile. 2. 3 B teres 4, 5 B tulda 6, 10 S. brachycladum 7. 8, B vulgarls 9 G, uerticillata. 11 S. jaculans 12, 13. T siamensis the upper and lower epidermis are distinct in all with bulliform cells on the upper and stomata on the lower Sclerenchyma humps are formed in some as seen in 9 and 1 1 Bundles are connected with epidermis by sclerenchyma pegs quacy in our knowledge is the general assumption that all is well with bamboos and they grow well naturally or in plantation. Only recently when the natural supply is running short or inadequate to meet the needs of the increasing population there is a renewed interest in increasing bamboo production. For the same reason, two international workshops have been conducted within a period of five years.

Perhaps there are no other single group of plants that display so many variable vegetative characters as bamboos and our knowledge about the developmental aspects of these is very limited.

The general organisation of shoot apex conforms to the pattern well known in angiosperms and there is only one earlier study on *Sinocalamus (= Bambusa) beecheyana,* distributed in China (Hsu, 1944). This work is not quoted in other works or easily missed for reasons unknown. The axillary bud development takes place early in the second or third leaf axils which is different from the majority of the species studied presently.

The shoot apex in woody monocotyledons is very interesting as recorded in the case of palms (Ball, 1941; Tan and Rao, 1980). The primary thickening meristem characteristic of palms (Ball, 1941) is absent in bamboos. The prominent tissues of the flank region, commonly seen in palms is seen presently only in case of *Bambusa vulgaris.* The differentiation of many procambial strands and the prominent peripheral meristem are similarities noticed between palm and bamboo shoot apices. The plicate leaf condition seen in other monocots is absent in bamboos (Periasamy, 1980).

Some of the bamboo shoots are very massive structures and they are very richly vascularised as evidenced by the formation of vascular strands. A detailed anatomical study to show the differences between the hard mature culm and the soft tissues in the bamboo shoots would be interesting and so also the node and internode development between the young bamboo shoots emerging at the ground level and the aerial wood culms. The environmental conditions under which these two develop are totally different.

The morphogenesis of different kinds of axillary buds, single or multiple, or those that give rise to leptomorph or pachymorph rhizomes will not only be very interesting to understand the growth habits of bamboos but also would help to improve their propagation by vegetative cuttings,

The stem structure is relatively well studied and four types of vascular bundles are recognised which also lend support to the systematics of the group (Liese, 1980; Holttum, 1958). The materials studied at present came from young stems and the number of sclerenchymatous caps or groups could not be clearly determined for this reason.

The bamboo leaf structure is similar to those of other grasses with characteristic bulliform cells, presence of larger air spaces and big vascular bundles with characteristic bundle sheaths (Esau, 1977). Many of these details are also recorded presently. The structural variations noticed between regular leaves and culm sheaths are interesting especially the differences in mesophyll and the nature of vascular bundles. Whether these differences are present in all the bamboos is yet to be determined and different types of sheathing organs should be studied in detail. The morphogenesis of different types of leaves will be interesting both from the descriptive and experimental points of view. It closely resembles heterophyllous condition since the same axis from rhizome to fleshy shoots to strong aerial axes produce three different types of foliar structures. This is an interesting problem to work with.

As an outcome of the previous workshop meeting in Singapore several important research needs and priorities were identified and recommended. Very briefly these include the following: a) Studies on culm anatomy to determine or correlate the strength and structural properties. b) Detailed studies on bamboo fibres. c) Factors responsible for natural regeneration in bamboos. d) Identifying the easily recognisable vegetative characters. e) Propagation by tissue culture and shoot culture for mass production and germplasm exchange. f) To use the juvenile tissues on the culm for large scale propagation. following the experiences gained in sugarcane. g) To identify very easy methods for vegetative propagation so that the bamboo industry can be revolutionised. h) Increasing the quantity of propagules/hectare. i) More frequent use of bud material for in vitro studies and a few others. The papers presented in the second workshop have provided a few or some answers and indicators to solve some of the problems posed earlier.

With the number of papers presented in the form of valuable contributions towards improving the quality and quantity of bamboos in Asia and with different suggestions made, we are now in a better position to plan further activities to achieve the objectives laid down. Foremost is the need to improve the basic work on bamboos and here we have to use the existing expertise in different countries so that no time or money is unnecessarily wasted by repeating the same research in four or five countries simultaneously, unless the nature of the problem is such that it needs attention by different people in several laboratories. Several models are already available like Asian Mangrove project supported by UNDP and others. Under this project both training and research programmes are included with the main objectives of improving the trained manpower for specific researches. Wherever possible, the skills of the staff already working need to be improved. New staff should be technically trained to work on bamboos. Improvement of bamboos in Asia can be launched as an international project and the different activities can be coordinated by one or two persons. Any money, manpower and efforts spent in this direction will pay rich dividends in the near future.

For many of the big world organisations such a project may be a very insignificant one and they may not have the necessary manpower which means establishing a new section to manage the project. By launching a new medium-sized project for three or four years many of such cumbersome procedures can be avoided which would also bring the desired results within a shorter period of time. Hopefully the benefits derived can be shared by all and many of the needs of poor rural people can be easily met.

Acknowledgements

I am grateful to Dr C B Sastry , IDRC, Singapore for inviting me to participate in the workshop meeting; to my colleagues Mr Johnny Wee, Mr Ong Tang Kwee and Mdm Chan Siew Khim for their technical help and the National University of Singapore for the award of research grant FSOF 3/80 under which this work has been carried out.

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Observations on Vascular Bundles of Bamboos Native to China

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Abstract

The arrangement of vascular *bundles, presence or absence of cortical air spaces, the extent* of parenchyma between *the* bundles *are used as the important criteria in the* present study of bamboo *types.* About 45 species of 10 genera are classified under four major types.

Using vascular bundle arrangement as the criterion in leptomorph rhizomes* of bamboos, ten genera and 45 species of bamboos native to China can be classified into the following four major types:

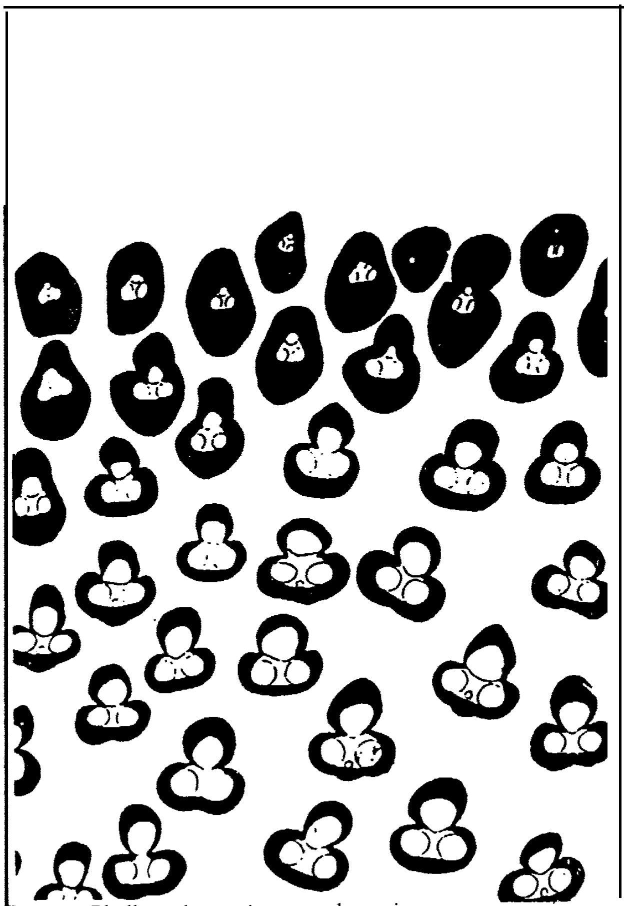


Fig 1. Phyllostachys nigra var. henonis.

Type I Vascular bundles are separated by parenchyma.

(A) No air canals in cortex (Fig. 1). Bamboos of this type are the following:- *Phyllostachys arcana, Ph. aurea, Ph. aureosulcata, Ph. bambusoides, Ph. bambusoides var. tanakae, Ph. bambusoides var. castilloni, Ph. bambusoides var. castilloni-inverssa, Ph. besseti, Ph. decora, Ph. dulcis, Ph. flexsuosa, Ph. glauca, Ph. glauca f. yunzu, Ph. meyeri, Ph. nigra, Ph. nigra var. henonis, Ph. nuda, Ph. nuda f. localis, Ph. viridis, Ph. platyglossa, Ph. praecox, Ph. prapinqua* and *Ph. pubescens.*

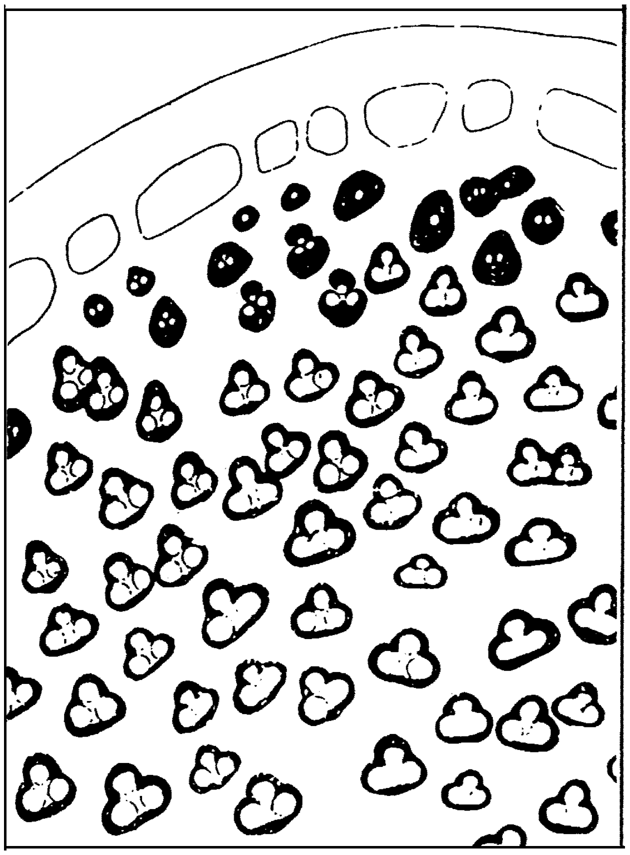


Fig. 2. Phyllostachys robvstiramea.

* Leptomorph rhizomes are the same as monoaxial and amphiaxial rhizomes. In China the bamboo rhizomes are divided into three kinds, moaoxial, amphiaxial and sympodial rhizomes

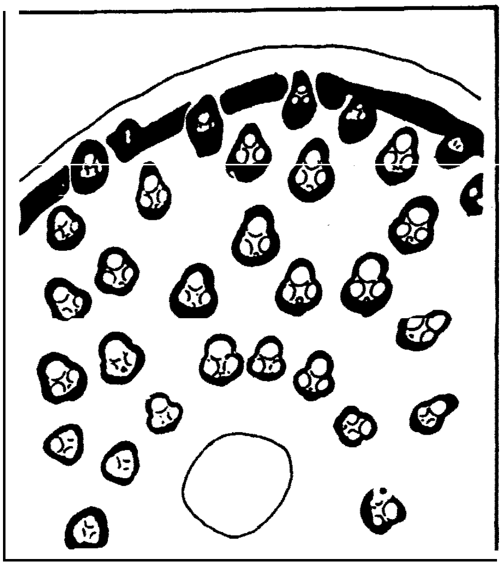


Fig. 3. Indocalamus victorialis,

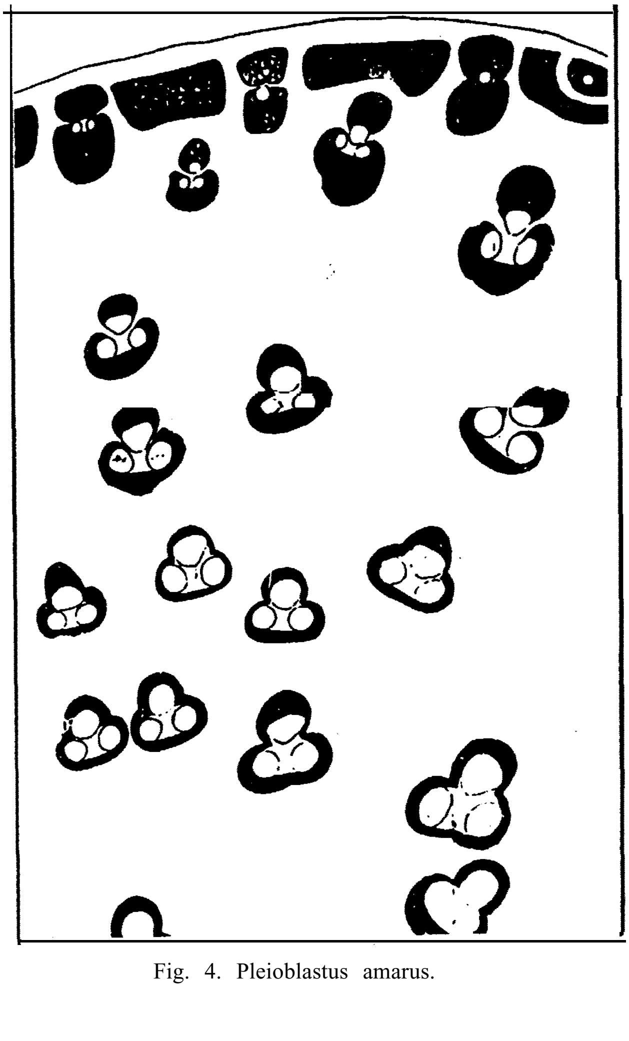


Fig. 4. Pleioblastus amarus.

(B) Air canals are present in cortex (Fig. 2). Bamboos of this type are listed as follows: : PhyllostAchys robustiramea.

Type II Vascular bundles are isolated. Between them, there are fibres — cell groups in rectangular, round, or variant forms, and they are never linked. These are mostly peripheral in position. No air canals in cortex (Figs. 3 and 4). Bamboos characteristic of this type are as follows: Indocalamus *longiauritus,* 1, victorialis, *Pleioblastus* amarus, PI. gramineus, *PI. sp., PI. sp., Psudosasa* amabilis and *Sinobambusa tootsik.*

Type III Vascular bundles are linked, occasionally with very narrow gaps of parenchyma interrupting Air canals in cortex (Fig. 5). This type includes: *Phyllostachys heteroclada* and Ph. nidularia.

Type IV Vascular bundles are connected in the form of a ring enclosing stele.

(A) No air canals in cortex (Fig. 6). Bamboos of this type are as follows: *Arundinaria* fargesii, Chimonobambusa utilis, Ch. quadrangular&, Ch. *purpurea, Qionzbuea lumidinoda, Sasa unbigena* and Sinarundinaria *fangiana.*

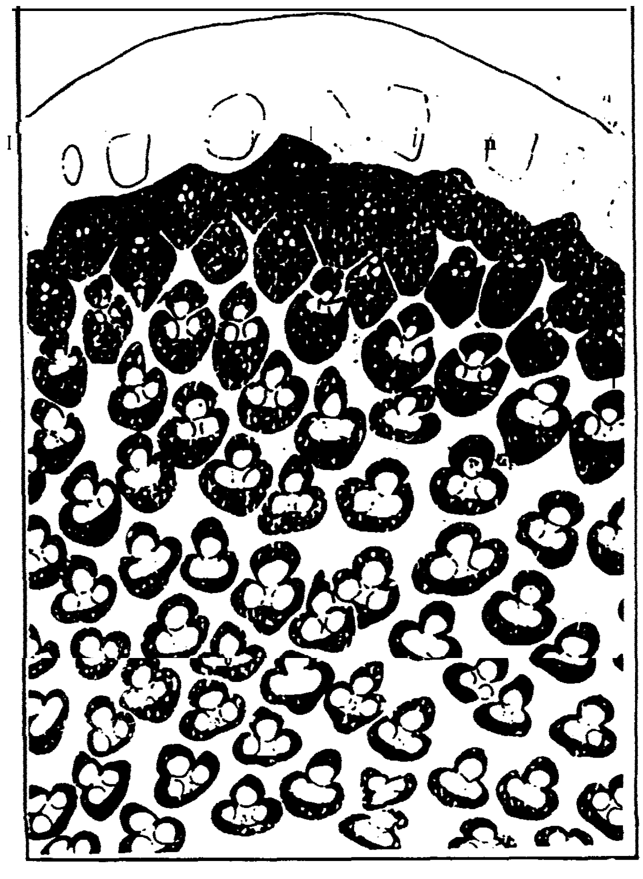


Fig. 5. Phyllostachys heteroclada.

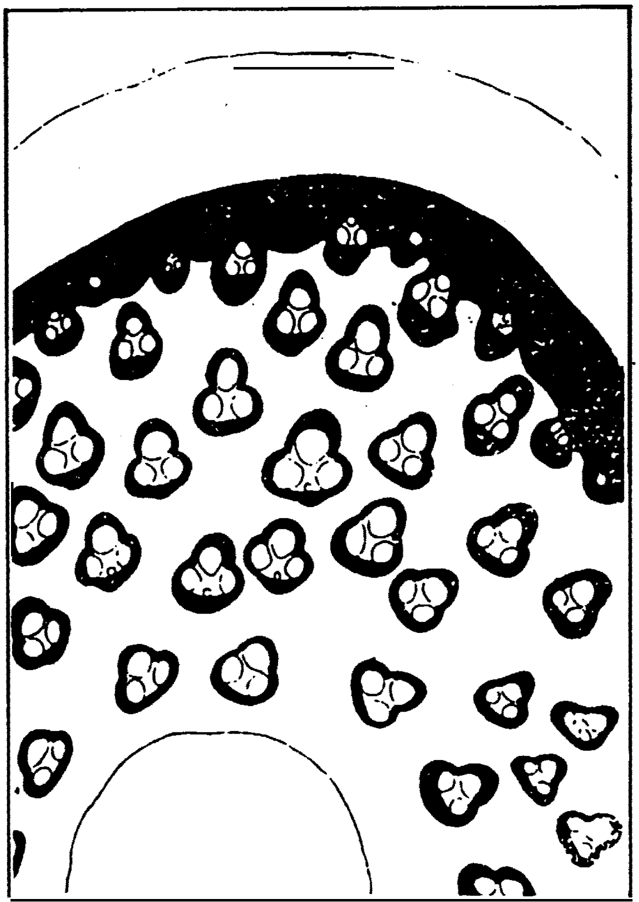


Fig. 6. Chimonobambusa utilis.

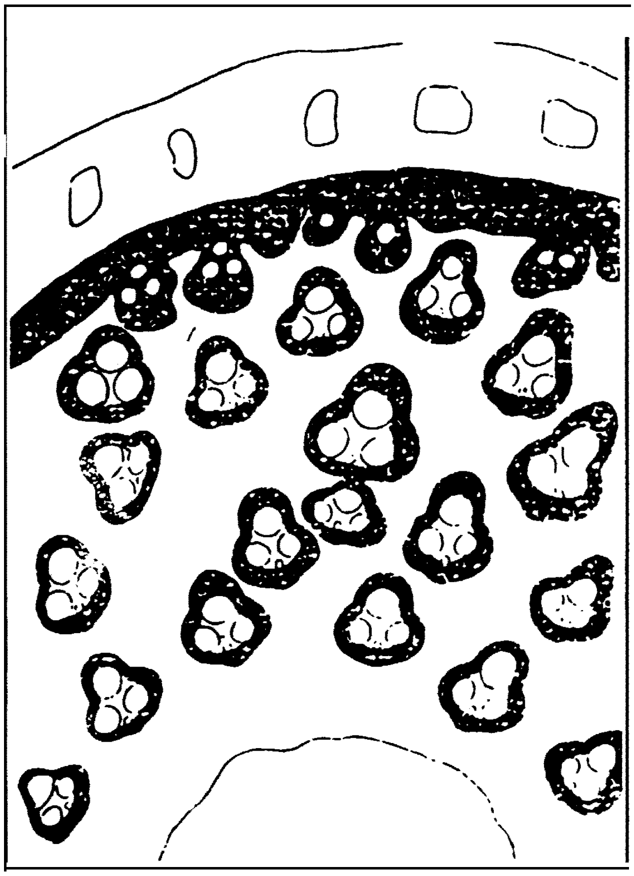
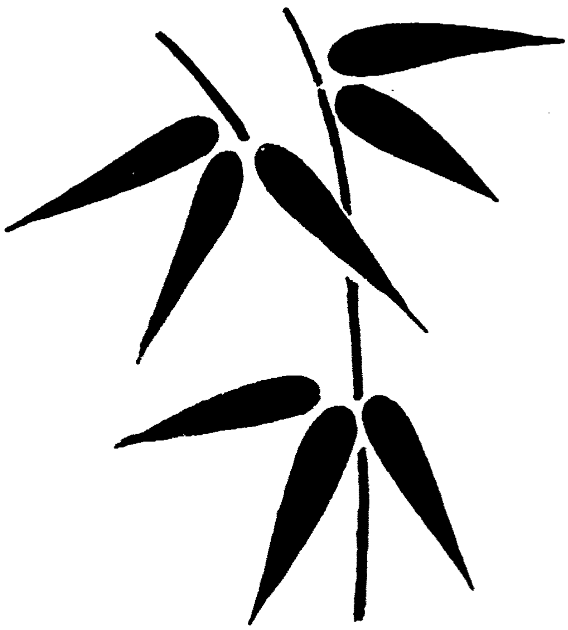


Fig. 7. Chimonobambusa szechuanensis.

(B) Air canals in cortex (Fig. 7). Bamboos of this type are: *Chimonobambusa szechuanensis* and *Qionzhuea opienensis.*

Observations have shown that there is correlation between vascular bundle arrangement mentioned above and with the other vegetative characters of a species. These are useful characters in classification and identification.



A Study on **the Anatomy of the Vascular Bundles of Bamboos from China**

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Abstract

This paper provides anatomical details of regular *vascular bundles of the culms of 28 bamboo genera with 100 species and five varieties from China, The characteristics of the vascular bundles from the outer wall to the inner wall are also illustrated for certain species and this data helps to show the* difference *between the* consanguinity of *the characteristics and morphology of the vascular bundles of bamboos of each genus. It also provides valuable reference for identifying bamboo material, articles made of bamboos, relics and fossils.*

The paper also describes a simple method ofpreparing and examining the cross sectional surface of bamboos. The method is convenientfor use infield examination.

The vascular bundles are categorized into five types, that is, the double broken type, broken type, slender-waist type, semi-open type and open type.

Variations in vascular bundles and their usefulness are mentioned.

The anatomical characteristics of the culm vascular bundles are an important supplement to the classification of bamboos and appropriale examples are given.

The variations in distribution and anatomical characters of Indocalamus and Sasa are discussed. *The vascular bundles of Sasa (inclusive of Sasamorpha) are all semi-open while those of Indocalamus are mostly open type. The arrangement of the vascular bundles of the genera is as follows: Indo-*calamus: *undifferentiated –* semi-differ*entiated – semi-open – open. Sasa (including Sasamorpha): undifferentiated* – semi-differentiated – semi-open.

Introduction

Anatomy of the vascular bundles of bamboo culm is a useful guide for bamboo taxonomy. The details can be used when some bamboos cannot be identified with their flowers. It is also used in identifying some bamboos from ancient cultural relics. In addition, the anatomical details will help to determine the splitting property, strength and the ratio of fiber strands of bamboo culm used by modern papermaking industry, handicraft industry and other bamboo processing industries. This article introduces a simple method for examining culm vascular bundles by using only a saw, a knife and a magnifying glass. First cut a culm into three sections, the upper, the middle and the lower part, then smooth the cut with a sharp knife and smear it with water. This will make the vascular bundles visible, if seen through magnifying glass. Bamboos can be identified on the basis of characteristics and features, arrangements and types of the vascular bundles. If the cross-sectional area of vascular bundle sheaths and the fiber strands are larger, then the bamboo wood is strong and contain a high percentage of fiber. If the vascular bimdles are evenly distributed the bamboo wood has a good splitting property.

Materials and Methods

The plant materials used in this study included 99 species and 5 varieties belonging to 28 genera collected between 1976 and 1983 in Zhejiang, Fujian, Guangdong, Yuennan, Jiangxi, Shichuan provinces in China. *Each* bamboo culm was cut into three sections, the. upper, middle, and the lower part, about 0.2-0.3 mm thick taken from 5 cm beyond culm nodes with a sharp knife. After being wetted, the section was observed under a microscope, 8 x 15, with a tessellated scale in its eye piece, and the figure was drawn on tessellated paper to the scale. Other techniques like micrography and tracing were also used. Serial of the vascular bundles from the sections on the outer wall to the inner wall of 3 segments were drawn, so that it could be well seen from the drawing, size and arrangement of the vascular bundles.

Collection of plant materials.

Test No.	Scientific Name	Place of Collection
2-1. 1.	Thyrsostachys siamensis Gamble	Yunnan Xishuangbanna
2-1 2.	Oxytenanthera *nigrocilliata* Munro	Yunnan Xishuangbanna
2-1. 3.	Gigantochloa ligulata Gamble	Yunnan Xishuangbanna
3-1. 4.	Dendrocalamus brandissi Kurz	Yunnan Tengchong
3-1. 2.	D. giganteus Munro	Yunnan Xishuangbanna
3-1. 3.	D. patellanis Gamble	Yunnan Mangshi
2-2. 4.	D. strictus *Nees*	Yunnan Xishuangbanna
2-2. 5,	D. *latiflorus* Munro	Fujian Futing
2-2. 6.	Neosinocalamus affinis (Munro) Keng f.	Zhejiang dinghai
3-1. 5.	N. distegius (Keng & Keng f.) Keng f. & Wen, ined.	Yunnan Kunming
3-1. 7.	N. beecheyanus (munro) Keng f. & Wen, ined.	Fujian Xiamen
2-3. 7.	Lingnania chungii McClure	Zhejiang Dinghai
3-l. 9.	L. wenchouensis Wen.	Fujian Futing
3-1. 10.	Bambusa basihirsuta McClure	Zhejiang Dinghai
3-1. 11.	B. breviflora Munro	Zhejiang Dinghai
3-1. 12.	B. dolichomerithalla Hayata	Zhejiang Dinghai
3-1. 13.	B. eutudoides McClure	Zhejiang Dinghai
3-1. 14.	B. gibbodes Lin	Zhejiang Dinghai
3-1. 15.	Bambusa glaucescens (Will) Sieb.	Zhejiang Xunan
3-1. 16.	B. glaucescens var. shimadia (Hayata) Chia ex But	Zhejiang Linhai
3-1. 17.	B. nana Roxb	Zhejiang Pujiang
2-3. 8.	B. pervariabilis McClure	Zhejiang Dinghai
3-1. 19.	B. textilis McClure	Zhejiang Wenling
3-1. 20.	B. textilis var. albo-stricta McClure	Zhejiang Xiamen
3-1. 21.	B. textilis var. glabra McClure	Zhejiang Dinghai
3-1. 22.	B. pachinensis var. hirsutissima (Odash.) Lin	Zhejiang Dinghai
3-1. 23.	B. tuldoides Munro	Fujian
3-1. 24.	B. vulgris Schrad	Yunnan Kunming
3-2. 25.	B. subtrimcata Chia ex Fung	Zhejiang Dinghai
3-2. 26.	B. lapidea McClure	Zhejiang Dinghai
3-2. 28.	B. oldhami Munro	Zhejiang Dinghai
3-2. 27.	B. prasina Wen	Zhejiang Fingyang
2-3. 9.	Dinochloa utilis McClure	Guangdon Hainan
3-2. 29.	D. orenuda McClure	Guangdon Hainan
3-2. 32	Cephalostachyum fuchsianum Gamble	Yunnan Mangshi
2-4. 10.	C. pergracile Munro	Yunnan Xishuangbanna
2-4. 11.	Melocanna humils Kurz	Fujian Xiamen
2-4. 12.	Schizostachyum pseudolima McClure	Yunnan Luxi
3-2. 35.	S. funghomii McClure	Yunnan Xishuangbanna
3-2. 33.	S. xinwuensis Wen	Jiangxi Xunwu
3-2. 34.	S. hainanensis Merr.	Jiangxi Xunwu
2-4. 13.	Ampelocalamus actinotrichus (Merr. & Chun) Chen. Wen ex Sheng	Guangdon Hainan
2-5. 14.	Chimonocalamus pa/lens Hseuh ex Yi	Yunnan Jinping

Test No.	Scientific Name	Place of Collection
3-2. 27.	*C. fimbriatus* Hseuh ex Yi	Yunnan Luxi
4-3. 31.	Ferrocalamus strictus Hseuh ex Yi	Yunnan Jinping
2-5. 15.	Fargesia farcta Yi	Yunnan Luxi
3-2. 39.	Fargesia ampullaris Yi	Yunnan Luxi
3-2. 40.	F. chungii (Keng) Wang ex Yi	Yunnan Mongshi
3-2. 41,	*F. grossa* Yi	Yunnan Lijiang
3-2. 42.	*F. setosa* Yi	Yunnan Zhongdian
3-2. 44.	*F. edulis* Yi	Yunnan Kunming
2-5. 16.	Yushania niitakayamensis (Hayata) Keng f.	Zhejiang Linan
3-2. 46.	Y. hirticaulis Wang ex Ye	Jiangxi
3-2. 45.	Y. wixiensis Yi	Yunnan
3-2. 47.	Y. hasihirsuta (McClure) Wang & Ye	Fujian Chongan
3-2. 48.	Y. confusa (McClure) Wang & Ye	Jiangxi Huangan
5-2. 81.	Chimonobambusa quadragularis Makino	Fujian Sanmin
4-2. 23.	C. setiformis Wen	Fujian Wuyishan
5-2. 83.	C. *conoolta* Dai ex Tao	Yunnan Luxi
5-2. 80.	C. armata (Gamble) Hsueh ex Yi	Guangxi Luye
4-1. 17.	*Indosasa crassiflora* McClure	Guangxi Nanning
5-l. 50.	*I. sinica* Chu & Chao	Yunnan Hekou
5-l. 51.	*I. shibataeaoides* McClure	Guangxi Guilin
5-l. 63.	*I. glabrata* Chu ex Chao	Fujian Wuyi
5-l. 60.	*Sinobambusa intermedia* McClure	Sichunan Changning
5-l. 54.	*Sinobambusa rubroligula* McClure	Guangzhou
5-1. 52.	*S. edulis* Wen	Yunnan Malipo
5-l. 57.	S. glabrecens Wen	Zhejiang Qinguan
5-1. 55.	*S. nephroaurita* Chu ex Chao	Guangxi quangzhou
5-l. 56.	*S. tootsik* var. *Ieata* (McClure) Wen	Fujian anxi
4-l. 18.	*S. tootsik* Makino	Fujian anxi
5-1. 58.	*S. anaurita* Wen	Jiangxi Jingangshan
5-l. 62	*S. giganteus* Wen	Zhejiang Longquen
4-1. 19.	*Semiarundinaria lubrica* Wen	Zhejiang Longquen
4-2. 20.	*Brachystachyum* densiflorum Keng	Zhejiang Jinghua
5-2. 71.	*Phyllostachys uiridis* (Young) McClure	Zhejiang Lin hai
4-2. 21.	*P.* heterocycla (Carr.) Matsum	Hangzhou
5-2, 70.	*Phyllostachys praecox* Chu ex Chao	Zhejiang Linhai
5-2. 72.	P. stimilosa Zhou et Lin	Zhejiang Linhai
5-1. 66.	*P.* heteroclada Oliv.	Zhejiang Linhai
5-l. 67.	*P. rubromarginata* McClure	Zhejiang Luoqing
4-2. 22.	*Pseudosasa amabilis* (McClure) Keng g.	Jiangxi
5-2. 74.	*P. longiligula* Wen	Guangxi Quanzhou
5-2. 75.	*P. contori* (Munro) Keng f.	Guangzhou
5-2. 76.	*P. orthotropa* Chen ex Wen	Zhejiang Taishun
5-2. 77.	*P. notata* Wang ex Ye	Fujian
4-2. 25.	*Pleioblastus amarus* (Keng) Keng f.	Fujian Jianyang
5-2. 86.	*Pl. chino* Makino	Fujian Xiamen
5-2. 87.	*PI.* ovatoauritus Wen, ined	Zhejiang Luoqing
5-2. 88.	*PI. hisiaenchuensis* Wen	Zhejiang Qingyuan
5-2. 89	*PI. kwangsiensis* Hsiung	Zhejiang Yongjia
5-2. 90.	*PI. matsunoi* (Makino) Nakai	Fujian Shanghang
4-3. 26.	*PI.* gramineus (Bean) Nakai	Guangzhou
5-2. 92.	*PI. oleosus* Wen	Jiangxi Fongxing
5-2. 93.	*PI. maculatus* (McClure) Chu ex Chao	Fujian Jiang ou
4-3. 27.	*Clauinodum bedogonatum* (Wang et Ye) Wen	Jiangxi Wuyishan

Test No.	Scientific Name	Place of Collection
4-2. 24.	*Oligostachyum sulcatum* Wang ex Ye	Fujiang Mingqing
4-3. 28.	Indocalamus tessellatus (Munro) Keng f.	Zhejiang qingtin
5-2. 98.	*I. longiauritus* Handel-Mazz	Jiangxi Daiyu
5-2. 97.	*I. latifolius* McClure	Jiangxi Xunwu
5-2. 96.	I. *mogoi* (Nakai) Keng f.	Fujian Wuyishan
4-3. 29.	*Gelidocalamus stellatus* Wen	Jiangxi Daiyu
5-1. 64.	*Sasa qingyuanensis* Hu	Zhejiang Qingyuan
4-3. 30.	*S. sinica* Keng	Zhejiang Linan

Variations in the Vascular Bundles

The vascular bundle includes both the conducting tissue and the mechanical tissue. Joining up the plant parts, the underground rhizomes and the upper leaves, as a whole, the vascular bundles transport nutrient solution by vessels and sieve tubes. Because of the large size of the bamboo plant the conducting tissue is reinforced by an outside mechanical tissue which may facilitate circulation.

Some species even have one or two fiber strands. The sectional area of these fiber strands is usually greater than that of the central vascular bundle. The parenchyma in the vascular bundles serves as a buffer zone contributing to the elasticity of the culms, without which the culms would be inflexible and brittle. Near the epidermis, there are generally one or two layers of fiber bundles, closely arranged giving mechanical strength. These are followed by one to three layers of semi-differentiated vascular bundles with incipient conducting tissue. Further inside are regular vascular bundles, generally in the central part of the culm section, two to ten in number.-The shape and arrangement of the vascular bundles near the inner wall are irregular, and the position of sclerenchyma bundle sheath varies from sideward to outward or inward.

Although the morphology of the vascular bundle varies a lot, it remains relatively stable within a given internode of a species.

The Evolution of the Vascular Bundle in Sympodial Bamboos

Sympodial bamboos are said to be comparatively primitive with wide range of differentiation. Based on vegetative characters the sympodials are divided into two groups, sympodial rhizomes with short necks (clump) and long necks (spreading). The former include genera *Thyrsostachys, Dendrocalamus,* Lingnania, *Bambusa, Ampelocalamus* and *Schizostachyum,* and the latter *Chimonocalamus, Fargesia, Yushania. Melocanna, Pseudostachyum etc. The* inflorescences are indeterminate as in *Bambusa, Dendrocalamus, Lingnania, Thyrsostachys* and determinate in *Ampelocalamus, Chimonocalamus, Fargesia, Yushania* etc. The anatomical details of the vascular bundles reflect the main evolutionary trends.

The sympodial genera that possess the double-broken and broken types of vascular bundle are *Thyrsostachys, Dendrocalamus,* Lingnania, Bambusa, Schizostachyum, *Gigantochloa, Oxytenanthera,* Neosino*calamus* etc.

Schizostachyum, Cephalostachyum, Melocanna are sympodial but taxonomists usually do not treat them as the same, but group them separatly as a tribe named Melocanneae or Schizostachyeae. This classification of a sub-tribe can be justified since all these genera have the bundles which are not the broken type but slender waist type. The sympodials with long necks like Fargesia and Yushania are distributed at high elevation with advanced indeterminate inflorescense which is considered more advanced than the sympodial with short neck type, also they have their representive vascular bundles as open or semi-open type and not slender waist type.

The Character of Vascular Bundles of Running Type Bamboos

The monopodial and amphipodial type of bamboos have long been classified into two major categories. The anatomical details of the vascular bundles are not distinct in these two categories. They both have open and semi-open type of vascular bundles, (except in few species of *Chimonobambusa).* Although *Phyllostachys* is a monopodial genus, sometimes we can also find species that have amphipodial rhizomes, such as P. heteroclada, P. bombusoides and P. makinoi. The anatomy of the vascular bundles of running type of bamboos is different from that of clump type. Besides, the form and structure of the vascular bundles are different from one another.

1) The typical semi-open type of vascular bundles are found in *Sass, Gelidocalamus, Semiarundinariu, Clavinodum,* Oligo-stuchyum, and the Subgen. *Pleioblastus, Pleioblustus gramineus, P. matsunoi* etc. Of these, Sass and *Semiarundinaria* consist of vascular bundles which are somewhat typical. In Sasa the upper, middle, or the lower part have about six bundles but in *Semiarun-*dinaria there are four vascular bundles in the upper part, five in the middle and eight in the lower part. The typical vascular bundles of *Gelidocalamus* are of semi-open type except those near the inner wall of the upper part of the culm which are of open type. The vascular bundles of Subgen. *Pleioblastus* are all of semi-open type.

2) The genera that have all or nearly all open -type vascular bundles are *Ferrocalamus, lndocalamus* and *Pseudosasa. Ferrocalamus* has clump type, but its rhizomes are amphipodial and the vascular bundle of the culms are of open type. The undifferentiated vascular bundles on the outer wall of the culms of *Ferrocalamus* are exceptionally big; therefore, the tissue in the wall is well developed and forms a strong and hard outer wall. Almost all the vascular bundles of *Pseudosasa* and *Chimonobambusa are* of open type. The regular vascular bundles of other genera are mainly open type.. In the process of changing from undifferentiated vascular bundles to regular ones, the semi-' open type gradually changes into open type. In this changing process Indocalamus usually shows semi-open type before the regular open type appears.

3) Open and semi-open type vascular bundles exist at the same time and sometimes they are of equal number, for example, *Phyllostachys, Brachystachyum* and species of Subgen. *Pleioblastus, as Pleioblastus amarus,* Pleioblustus hsienchuensis, Pleioblastue oleosus and Pleioblustus maculatus. Phyllostachys is intermediate among the running type, that is to say, the typical open type vascular bundles of *Phyllostachys* are nearly as many as the semi-open ones. The regular vascular bundles of *Brachystachyum* are mainly of open type, while those of Subgen. *Pleioblastus* are mainly semi-open type.

4) Regular vascular bundles are mainly of open type, but sometimes near the inner wall and outer wall of the culms semi-open type vascular bundles are found, and among the groups of vascular bundles there are layers of parenchyma. These can *also* be found in both *Indosasa* and *Sinobambusa,* which show that the two genera not only look alike in their appearances but also have similar vascular bundle features.

A Generic Key to the Vascular Bundles of Bamboos

1. The culm vascular bundles is broken once or twice in the middle and the lower or upper parts of the central vascular bundle has a proliferation of fibre strands,

2. Co-existance of the broken type and double broken type of vascular bundles.

3. The lower part of the culm with the double broken type vascular bundles, the middle and upper parts with the broken type vascular bundles.

4. The vascular bundles of the lower part of the culm are mostly double broken type.

5. The lower part of the culm with a considerable number of vascular bundles, the upper and middle parts with a sudden reduction of vascular bundles, the lower part with vascular bundles over twice as many as those in the. upper and middle parts **.** *Thyrsostachys*

5. The lower part of the culm with many vascular bundles, but gradually reducing from

the middle part upwards . . . . . . Gigantochloa

4. The lower part of the culm with few double broken type vascular bundles.

5, The lower part with outer vascular bundle sheath developed particularly well and its section area is larger than the sum total of other vascular bundle sheaths , ... * . . . . Dendrocalamus

5. The lower part of the culm with outer bundle sheath particularly well-developed and its section area is as large as that of the left and right side vascular bundle sheath or smaller . . . . *Oxytenanthera*

3. The lower and middle parts or only the middle part of the culm with the double broken type vascular bundles.

2. The culm with the broken type and without the double broken type vascular bundles.

3. In the middle of the cross section surface of the upper, middle and lower parts of the culm or near the inner wall, scalariform vessels are specially big . . . . *Lingnania*

3. Scalariform vessels of the vascular bundles of the culm are of the common size.

4, One open type vascular bundle near the inner wall . . . . , . . . , . . . *Neosinocalamus*

4. Two open type vascular bundles near the inner wall are changeable (a few species with the double broken type vascular bundles). . . . .*.......*.....*.... *Bambusa*

1. Vascular bundles of the culm do not break, fibre strands do not proliferate at the upper and lower parts of the central vascular bundle.

2. With the slender-waist type vascular bundles.

3. The lower part of the culm with a row of over ten vascular bundles, the upper and middle parts with a sharp reduction . . . .*....*...*....*. Cephalostachyum

3. The lower part of the culm with relatively fewer vascular bundles, the vascular bundles in the upper, middle and lower parts are almost equal in number.

4. Culms slender but with fairly big vascular bundles, the inner sheaths of vascular bundles near the inner wall are normal , ...- . . . . I . . . . ' . . . . . . Melocanna

4. Culms thick but with. comparatively small vascular bundles, the inner sheaths of vascular bundles near the inner wall are undeveloped . . . . *Schizostachyum*

2. With the open type and semi-open type vascular bundles.

3. With the open type regular vascular bundles.

4. The undifferentiated and semi-differentiated vascular bundles are especially well-developed, the sectional area of sclerenchyma is one to three times the size of the regular vascular bundles . , ... *Ferrocalamus*

4. The undifferentiated and semi-differentiated vascular bundles are a little bigger than regular vascular bundles.

5. The outer vascular bundle sheath of the semi-differentiated vascular bundle is especially well-developed. and is one to three times as big as other vascular bundle sheaths . . . . *Pseudosasa*

5. The outer vascular bundle sheath of the semi-differentiated vascular bundle is almost as big as or a little bigger than other vascular bundle sheaths . . . . *Chimonobambusa*

3. All the vascular bundles are semi-open.

4. The semi-differentiated vascu tar bundles are two times bigger than regular bundles . . . . , , . . *Gelidocalamus*

4. The semi-differentiated vascular bundles and regular vascular bundles are almost equal in number.

5. A row of about three to four vascular bundles, amphipodial rhizomes . , , . Subgen. *Pleioblastus*

5. A row of more than five vascular bundles.

6. The lower part of the culm with a row of five to six vascular bundles.

7. Semi-differentiated vascular bundles, and the inner vascular bundle sheath is almost rectangular.. . . . . , ... *Yushania*

7. Semi-differentiated vascular bundles, and the inner vascular bundle sheath is triangular . . . . Sasa

6. The lower part of the culm with a row of seven to eight vascular bundles, the inner sheath of the semi-differentiated vascular bundle is triangular, the outer sheath is oval . . . . *Semiarudinaria*

3. The open type and the semi-open type vascular bundles coexist.

4. Mainly with the semi-open type vascular bundles.

5. The vascular bundles in the lower part of the culm are all semi-open, near the inner wall of the upper and middle parts are two or three open type vascular bundles . . . Fargesiu

5. Near the inner wall of the upper, middle or lower part are one to two open type vascular bundles.

6. The inner vascular bundle sheath of the semi-open type vascular bundle in the three parts of the culm is triangular. . . . , . . Subgen. *Amarus*

6. The characteristics and morphology of the inner vascular bundle sheath of the semi-open type vascular bundles are irregular . . . . *. *Clavinodum*

4. Mainly with the open type vascular bundles.

5. The semi-differentiated vascular bundles and the regular vascular bundles are almost equal in size . . . . . , ... *Phyllostachys*

5. The semi-differentiated vascular bundles are bigger .than regular vascular bundles.

6. The outer sheath of the semi-differentiated vascular bundle is almost as big as the outer sheath of the regular vascular bundle . . . .'......*Zndocalamus*

6. The outer sheath of the semi-differentiated vascular bundle is quite well-developed, and far bigger than the outer sheath of the regular vascular bundle . . . *Brachystachyum*

4. The open type and the semi-open type vascular bundles coexist; sometimes there are parenchyma cell rings among groups of vascular bundles or the open type vascular bundles among the semi-open type vascular bundles.

5. The vascular bundles in the upper middle and lower parts of the culm are in a ratio of 4:5:9. shaped like an upside-down pagoda . . . . *lndosasa*

5. The vascular bundles in the upper, middle and lower parts of the culm are in a ratio of 6:8:8. almost equal in number . . . . _ . . . . * . . . . *Sinobambusa*

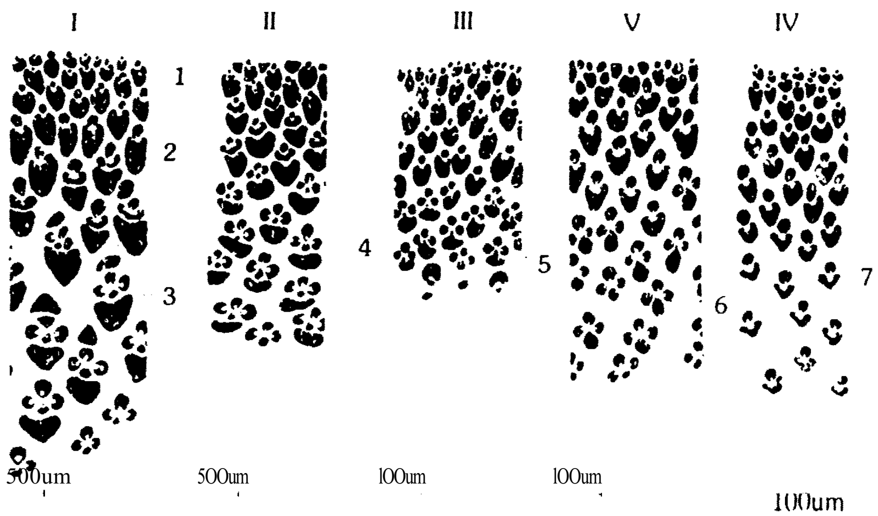
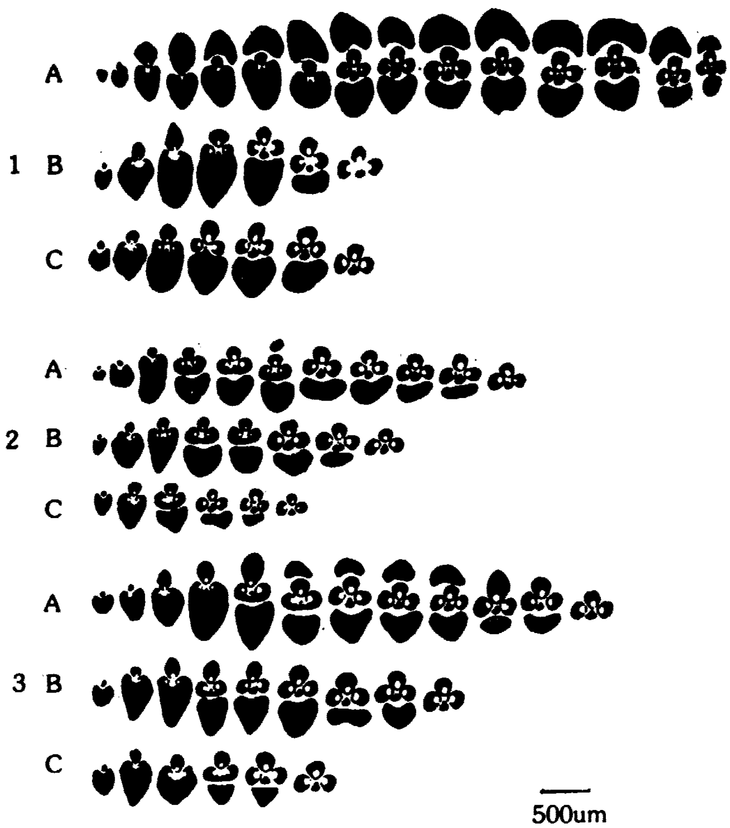


Fig. 1. Morphology of vascular bundles of bamboo. I. Dendrocalamus strictus Nees. II. Bambusa peruariabilis McClure. III. Melocanna *humilis* Kurt. IV. *Phyllostachys oiridis* (Young) McClure. V. Fargesia farcta Yi.
1. non-differentiated vascular bundles; 2. semi-differentiated vascular bundles; 3. double-broken vascular bundles; 4. broken vascular bundles; 5. slender waist vascular bundles: 6. open vascular bundles; 7. semi-open vascular bundles.



Fii. 2-1. sections of the upper, middle and lower of bamboo culm from left to right is outside to inner wall. 1. Thyrsostachys siamensis Gamble; 2. Oxytenanthera nigrocilliata Munro; 3. Gigantochloa *ligudata* Gamble. A. lower of culm; B. middle of culm; C. upper of culm.

Fii. 2-2. 4. Dendrocalamus atrictus Nees; 5. Dendrocalamus latiflotus Munro; 6. Neosinocalamus affinis (Mumro) Keng f .

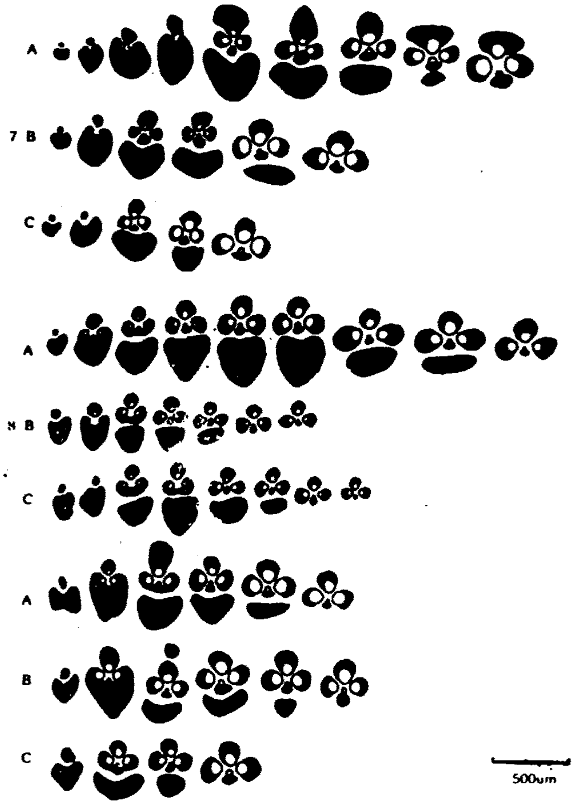


Fig. 2-3. 7. *Lingnania chungii* McClure; 8. *Bambusa pervariabilis* McClure; 9. *Dinochloa utilis* McClure

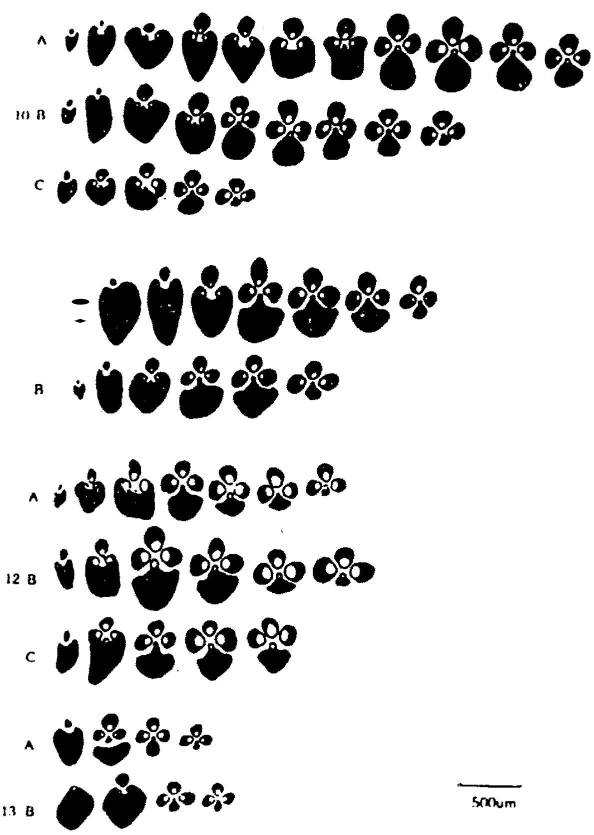


Fig. 2-4. 10. *Cephalostachyum pergracile* Munro; 11. *Melocanna humilis* Kurz; *ta*
McClure; 13. *Ampelocalamus actinotrichus* Chen, Wen et Sheng.

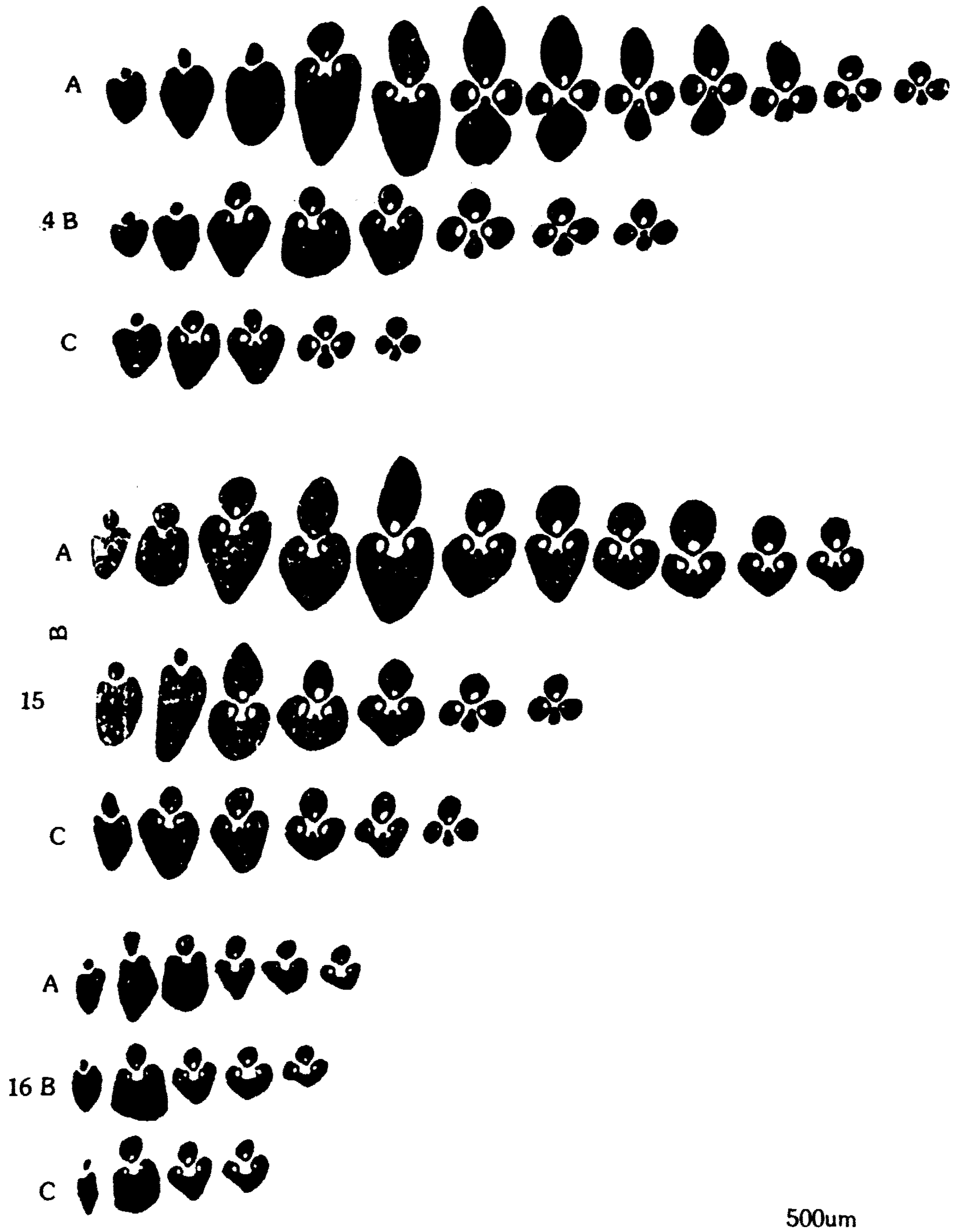


Fig. 2-5. 14. Chimonocalamus pal/ens Hseuh et Yi; 15. Fargesia farcta Yi; 16. Yushania niitakayamensis (Hayata) Keng f.

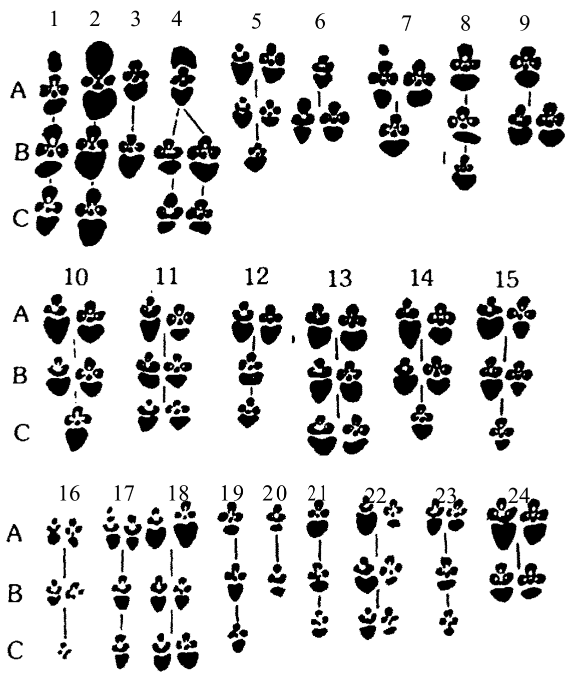


Fig. 3-1. The morphology of vascular bundles of bamboos. ali the test No. 1-24, see the table. A. lower of culm; B middle of culm: C. upper of culm

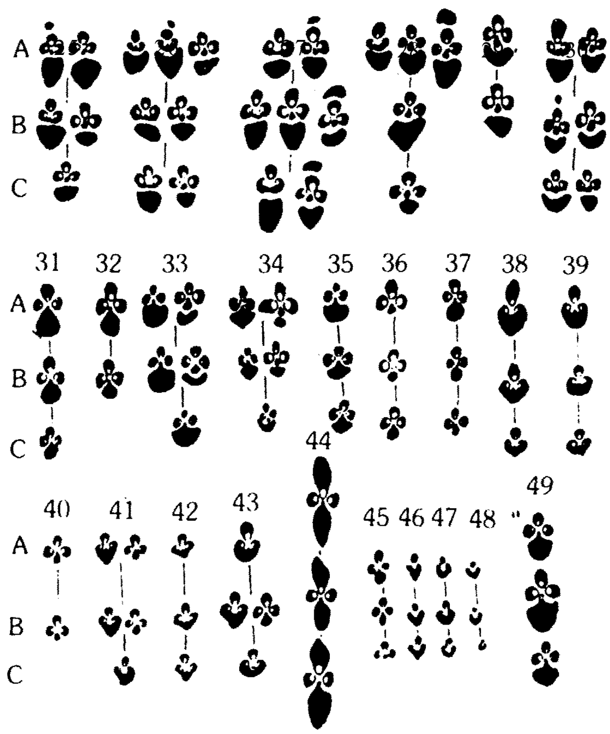


Fig 3-2 The morphology of vascular bundle of bamboos. all the test No 25-48, see the table, A lower of culm. B middle of culm. C lower of culm

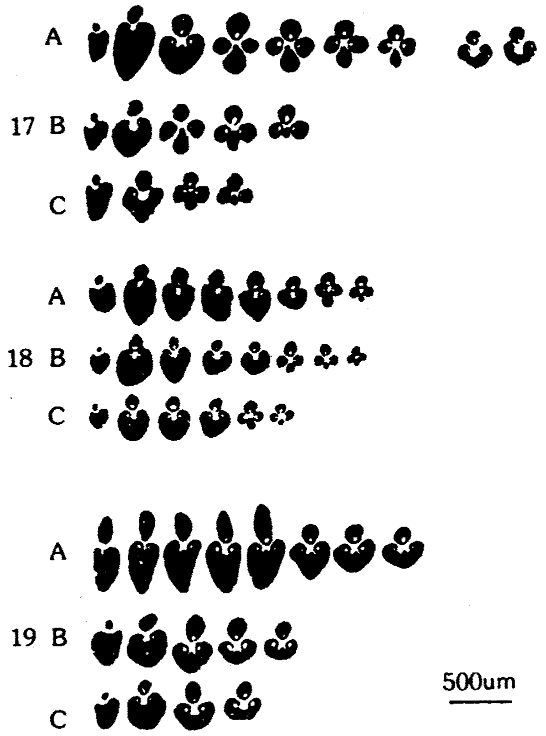


Fig. 4-l. Sections of the upper, middle and lower of bamboo culm, from left to right is outside to inner wall. A. lower of culm; B. middle of eulm; C. upper of culm. 17. Indosasa crassifllora McClure; 18. *Sinobambusa tootsik* Makino; 19. Semiarundinaria lubrica Wen.

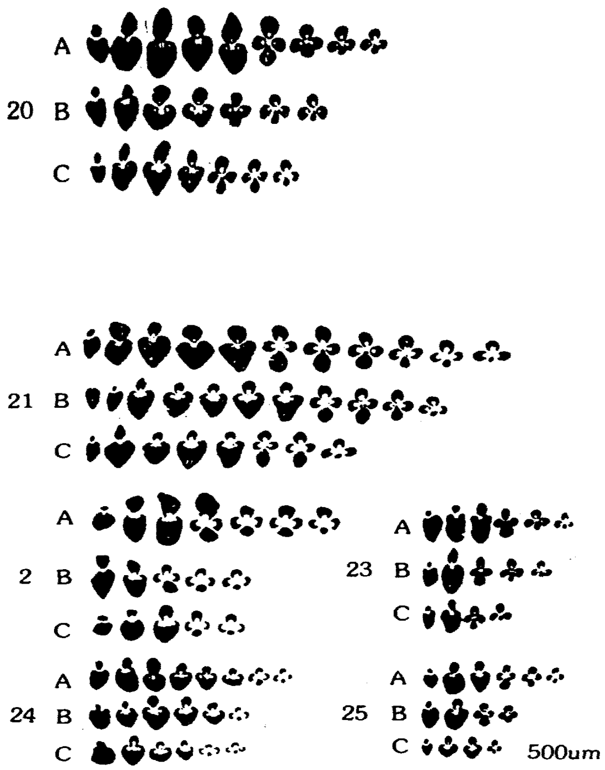


Fig. 4-2. 20. Brachystachyum densijjorum Keng; 21. *Phyllostachys heterocycla (Carr.)* Matsum; 22. Pseudosasa amabilis (McClure) Keng f.; 23. Chimonobambusa *marmorea* Makino; *24. OIigostochyum sulcatum C.P.* Wang et *Ye; 25. Pleioblastus amarus* (Keng) Keng f.

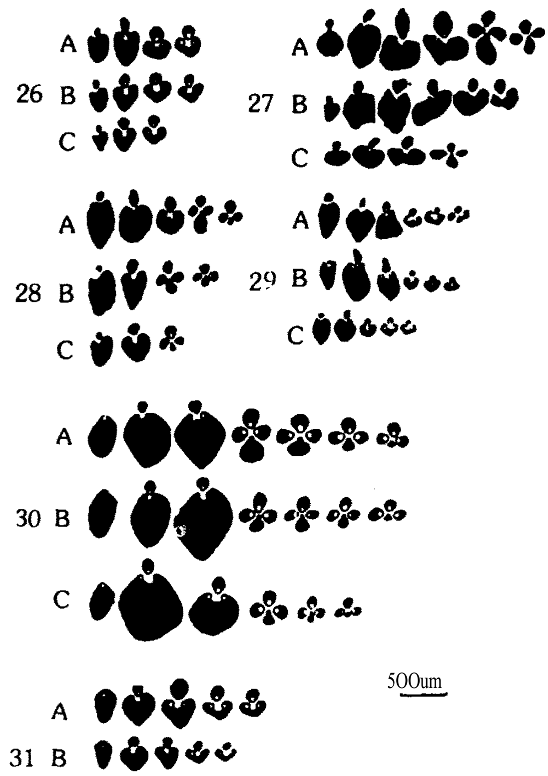


Fig. 4-3. 26. Pleioblastus gramineus (Bean) Nakai; 27 Clauinodum oedogonotum (C.P. Wang et Ye) Wen; *28. Indocalamus tessellatus* (Munro) Keng f.; 29. Gelidocalomus stellatus Wen; 30. Sasa sinica Keng; 31. Ferrocalamus strictus Hsueh et Kens. f.

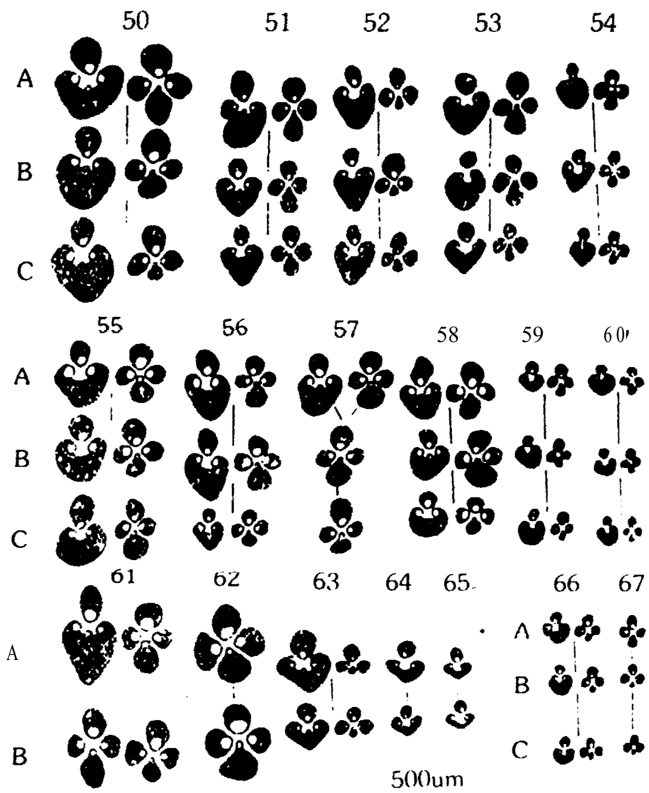


Fig. 5-l. The morphology of vascular bundle of bamboos, all the test No. 50-67. see the tables
A lower of culm; B. middle'of culm; C. upper of culm

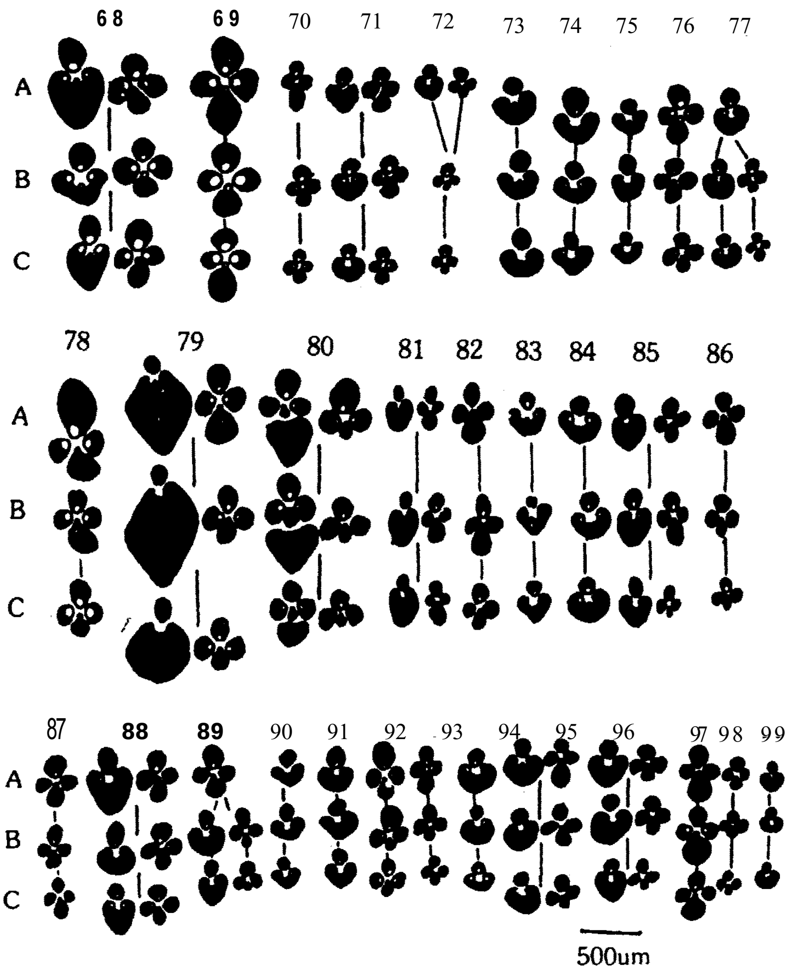


Fig. 5-2. The morphology of vascular bundle of bamboos. all the test No. 68-99. see the tables. A. lower of culm; B. middle of culm; C. upper of culm. (The construction of the key is left in its original form but this can be further simplified References, other detaib and explanations connected with this paper can be obtained from the authors — Eds).

Anatomical Properties of Some Bamboos Utilized. in Indonesia

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Abstract

Four species of bamboo (i.e. Dendrocalamus giganteus, Dendrocalamus asper Gigantochloa robusta, Bambusa vulgaris, oat. *striata)* utilised in Indonesia are studied anatomically and the results are correlated to their mechanical properties. There is a correlation between fiber length, modulus os elasticity and compression strength.

Introduction

Among the sixteen species of bamboo utilized in Indonesia (Widjaja, 1980), ten of them (i.e. *Gigantochloa apus* (Schult. & Schult.) Kurz, . *Gigantochloa verticillata* (Munro*), *Gigantochloa robusta Kurz, Gigan-*tochloa *atter* (Hassk.) Kurz, *Dendrocalamus asper* (Schult.) Backer *ex* Heyne, *Bambusa* arundinacea (Retz.) Willd., Bambusa vulgaris Schrad. var. *striata, Bambusa blumeana* Schult., *Gigantochloa aff. atter** and *Bambusa polymorpha* Munro) are useful in the building construction, (• hereafter referred to as *Gigantochloa pseudoarundinacea* (Steud.) Widjaja and *Gigantochloa* atroviolacea Widjaja respectively). Their mechanical properties, however, have yet to be determined. Grosser & Liese (1974) concluded that the percentage of sclerenchyma fibres increases from the bottom to the top of the culm, accompanied by compression strength. Janssen (1981) pointed out that the bending stress decreases with the height of the culm but the modulus of elasticity increases with the latter. Kawase (1981) reported that the fiber size in the middle part of culm is greater than in the bottom and the top, and that the outer part of the culm has longer fibers than the inner part.

In this paper, the correlation between the fibre length and the mechanical properties (including compression strength, tensile strength, static bending strength and stiffness) of *Dendrocakamus asper, Gigantochloa robusta, Bambusa vulgaris* var. *striata* and *Dendrocalamus giganteus,* is studied. Although *D. giganteus* is not cultivated outside the botanical gardens in Indonesia, it is included in this study because of its potential value for building purposes.

Materials and Methods

This study was based on 4 species of bamboos grown in the Bogor Botanical Gardens.

Samples were obtained by taking the nodes at the height of 1.5 m above the ground. By counting that node as the first one, further samples were also taken from the third, fifth and seventh nodes further up of the culms. For studying the fibre length, pieces of culm were macerated in 50% HNO_3 at 50°C for 15 minutes. After washing in distilled water it was stained with 1% methylgreen in 10% acetic acid and mounted in 50% glycerin. The mechanical properties of the culm was determined by Baldwin instrument (to measure the tensile strength) and Amsler 6000 kg (to measure the static bending strength and the compression strength). The samples used for this study measured 30 cm x 2 cm x 0.5 – 1 *cm,* following the American Standard for Testing and Materials ASTM D 143 52 (1972) with some modification.

Results and Discussion

Anatomical properties: The fibre length showed that Dencrocalamus asper has the longest fiber (averaging 20.03 mu), followed by Bambusa vulgaris var. striata (18.92 mu, Dendrocalamus giganteus (18.84 mu), and Gigantochloa robusta (18.12 mu). Based on the position along the culm, the first node studied generally has similar fiber sizes (19-20 mu). The fiber length in the third node and above do not show a genera1 pattern (Table 1).

Mechanical properties: Sjafii (1984) showed that Dendrocalamus giganteus has the highest specific gravity (0.7 1) if compared to Dendrocalamus asper (0.61) Giganto-chloo robusta (0.55), and Bambusa vulgaris var. striata (0.52). However, there is no significant difference between various nodes of every species. With regard to the average rate of the modulus of elasticity, modulus of rupture and compression strength, Dendrocalamus giganteus also has the highest value, followed by Dendrocalamus asper, Gigantochloa robusta and Bamb'usa vulgaris var. striafo (Table 2). The tensile strength of Dendrocalamus giganteus (1907.33 kg/cm^2) is smaller than Dendrocalamus asper

Table 1. Fiber length at various nodes of culm

Species	Node	Fiber Length	Average
D. giganteus	1st	19.16	
	3rd	18.04	
	5th	19.16	18.84
	7th	19.0	
D. asper	1st	19.28	
	3rd	19.60	
	5th	21.16	20.03
	7th	20.10	
G. robusta	1st	19.66	
	3rd	15	
	5th	19.66	18.12
	7th	18.16	
B. vulgaris var *striata*	1st	19.92	
	3rd	20.24	
	5th	18.2	18.92
	7th		17.2

Table 2. Mechanical properties of various bamboos at various nodes (after Sjafii. 1984)

Species	Part of culm	Modulus of elasticity kg/cm^2	Modulus of rupture kg/cm^2	Compression strength kg/cm^2	Tensile strength kg/cm^2
D. giganteus	1	172097.92	1828.57	602.56	1836.16
	3	122463.95	1758.28	619.88	1945.91
	5	147912.10	1827.90	639.95	1880.20
	7	130352.42	2880.13	645.84	1965.87
	Average	143206.60	1823.72	627.02	1907.04
D. asper	1	122073.82	1637.81	639.30	2145.03
	3	149587.06	1741.61	592.35	2040.15
	5	129542.12	1595.74	622.20	2219.89
	7	123966.17	1578.62	565.93	2103.97
	Average	131292.29	1638.45	604.95	2127.26
G. robusta	1	94208.59	1384.48	533.12	1970.51
	3	92367.13	1294.27	509.97	1766.82
	5	109217.50	1398.23	510.95	1853.65
	7	97381.90	1345.62	529.62	2066.33
	Average	98293.78	1355.65	520.92	1914.33
B. vulgaris	1	60652 -42	1075.01	484.30	1391.94
		71931.76	1123.66	443.02	1196.15
var. striota		88297.55	1105.27	475.34	1351.66
	7	83939.92	1286.24	417.43	1346.46
	Average	76205.41	1147.54	455.02	1321.55

Table 3. Correlation betweenFiber length and E-Modulus, R-Modulus, Compression Strength and Tensile Strength

Linear Regression	Correlation Coeficient	F
E-Modulus: 30.568,72 + 4162.96 Fiber length	0.3	8.48' .
R-Modulus: 1485.08 + 0.33 Fiber length	0.0001	0.00096
Compression strengh: -42.69. + 31.33 Fiber length	0.03	11.09' .
Tensile strength: 1599,76 + 13.45 Fiber length	0.1	0.99

(2127.26 kg/cm and Gigantochloa robusta (1914.33 kg/cm^2), with *Bambusa vulgaris* var. *striata* has the lowest tensile strength (1321.55 kg/cm^2), The. result of the test of modulus of elasticity of *Bambusa vulgaris* var. striata. supports the findings of Limaye (1952), Janssen (1981) and Kawase (1981) who showed that the elasticity of the Iower culm is smaller than the upper one. The modulus of rupture of the 4 species studied also bears out the conclusion of Limaye (1952) who pointed out that the decreasing of moduilus of rupture follows the decreasing of specific gravity. The compression strength of *Dendrocalamus giganteus* and *Gigantochloa robusta* increases from the bottom to the top but not *so* in *Dendrocalamus* asper and *Bambusa vulgaris* var. striata. As pointed out by Limaye (1952) and Janssen (1981) the compression strength as well as the percentage of sclerenchyma fibre increase from the bottom to the top. According to Sjafii (1984), the modulus of elasticity can be used for detecting the modulus of rupture due to the highest correlation. Also, the compression strength and the tensile strength can be detected by the modulus of elasticity although the correlation is very small. Further analyses of the data obtained on the four e species studied indicate that the fiber length have a correlation with the modulus of elasticity and compression strength (Table 3) although it is very small- in the latter (r = 0.03). Further studies along these lines are now in progress on other species of utilized bamboos in Indonesia and it is hoped that the result will be beneficial in utilizing the anatomical properties for practical purposes.

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Fibre Morphology and Crystallinity of Phyllostachys pubescens with Reference to Age

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Abstract

The fibre form and crystallinity of Phyllostachyus pubescens we determined in relation to the age of the culm. This study helps to determine the age of the bamboo harvest.

Introduction

For purpose of investigating the fiber form and the relative crystallinity of cellulose of *Phyllostachyus pubescens* Maze1 ex H. de Lehaie, culms of different ages were used. The bamboo grows rapidly, and the different samples taken indicate the change of fiber form at each stage of growth in relation to its age.

Materials and Method

The materials were obtained from the stands of *P, pubescens* (from 1/2 1, 3, 7 years old) growing in Zhejiang province. From each bamboo culm, three portions from the base, the middle and the top were cut off. After air-drying, specimens of 2-3 cm in length were prepared from the central part of each joint. From the thick parts of the bamboo culm, specimens were taken, and named T_1, T_2, T_3, – and R_I, R_2, R_3 – for the tangential and radial faces respectively. The thin parts were divided into three parts, namely outside (To, Ro), middle (T_m,, R_m) and inside (T,, R,) .

The fibre form was examined according to the standard practice.

Each sample of crystallinity was crushed into powder with 80-100 mesh. The powder was dried over phosphorus pentoxide in vacuum at room temperature. Five hundred mg of the mixed powder was taken, pressed into tablet, and used for the x-ray measurement of crystallinity.

Results and Conclusion

The results (Table 1) (Fig. 1) show that average fiber length of bamboo is about 2 mm, average diameter is about 10.5-15.3 urn, double wall thickness is about 8-13.64 urn, and the ratio of length to breadth is over 100.

The fiber length of *P. pubescens* increases and the relative crystallinity decreases respectively with increasing age of the plant. In bamboos older than one year, the lignin content remains stable or rises slightly with years. The main structure, composed of cellulose fibers, are formed at an earlier period. Cell-wall growth and lignification proceed gradually.

Bamboo grows to full size within about 2-3 months, but it needs about 3 years for complete maturation of tissues. It means that bamboos that complete their growth and rotation at the end of this period or stage is considered satisfactory.

It is concluded that the study of fibre length variations would help to determine the period of harvest and recycling.

Table 1. Change on Fibre Form and Crystallinity of *P. pubescens* of Different Ages.

Age	Sample		Length (um)			Width (um)			Thickness of 2 walls (um)				Relative Crystallinity (%)
			$\bar{x}$	σ_{n-1} (s)	$\frac{s}{\bar{x}}100$	$\bar{X}$	σ_{n-1} (s)	$\frac{s}{\bar{x}}100$	$\bar{X}$	σ_{n-1} (s)	$\frac{s}{\bar{x}}100$	L/D	
	Base	Outer	1962	417.4	21.3	13.6	3.39	25.0	10.1	3.39	33.7	149	
		Middle	1666	373.4	22.4	13.6	4.39	32.3	9.2	3.57	39.0	123	
		Inner	1474	524.0	35.6	12.0	2.44	20.3	8.0	2.71	34.0	123	
		Outer	1742	709.7	40.7	14.3	3.20	22.4	10.8	3.34	30.8	122	
6 months	Middle	Middle	1628	631.8	38.8	14.0	3.78	27.0	10.6	2.46	23.2	116	63
		Inner	1612	655.5	40.7	13.4	3.08	23.0	9.9	2.65	26.9	120	
	Top	Outer	1506	606.6	40.3	12.1	3.30	27.2	10.0	2.93	29.5	124	
		Middle	1436	628.7	43.8	12.9	3.47	26.9	10.8	3.11	28.9	111	
		Inner	1566	655.8	41.9	12.5	3.08	24.7	10.8	2.97	27.5	125	
	Base	Outer	2186	699.6	32.0	14.5	4.02	27.7	12.6	3.83	30.3	150	
		Middle	2306	716.1	31.1	15.3	4.01	26.2	13.6	3.76	27.5	151	
		Inner	1790	508.4	28.4	13.9	4.05	29.2	12.3	3.87	31.4	129	
		Outer	1936	554.3	28.6	13.8	3.10	22.5	12.2	3.02	24.8	140	
1 year	Middle	Middle	2084	679.2	32.6	13.8	3.37	24.5	11.8	3.17	26.9	151	60
		Inner	1850	639.6	34.6	13.0	2.77	21.1	11.4	2.59	22.8	141	
	Top	Outer	1784	520.0	29.2	10.5	2.64	25.2	9.1	2.53	27.9	170	
		Middle	1942	507.9	26.2	11.8	3.00	25.5	10.0	2.88	28.9	165	
		Inner	1838	550.7	30.0	10.8	3.27	30.3	9.1	3.27	35.7	170	
	Base	Outer	2078	540.0	26.0	13.9	3.27	23.5	12.1	3.14	25.9	149	
		Middle	2136	547.3	25.6	11.5	2.82	24.6	9.8	2.82	35.5	186	
		Inner	1874	505.8	27.0	11.7	2.38	20.3	10.0	2.36	23.7	160	
		Outer	1917	603.1	31.5	14.8	2.67	18.1	12.9	2.65	20.6	130	
3 years	Middle	Middle	2140	594.5	27.8	12.6	2.88	22.8	11.1	2.97	26.7	169	58
		Inner	1908	424.2	22.2	11.7	2.30	19.7	10.1	2.26	22.5	163	
	TOP	Outer	2032	623.8	30.7	12.7	2.68	21.2	10.9	–	–	160	
		Middle	2244	572.9	25.5	12.1	2.56	21.1	10.5	2.53	24.2	185	
		Inner	2098	576.9	27.5	11.3	2.51	22.3	9.7	2.48	25.5	186	
	Base	Outer	2000	562.8	28.1	12.1	2.65	22.0	10.5	2.64	25.2	1166	
		Middle	2080	603.1	29.0	11.2	2.28	20.3	9.6	2.23	23.4	186	
		Inner	2054	583.2	28.4	11.3	2.37	21.0	9.7	2.25	23.3	182	
		Outer	2328	639.2	28.6	12.6	2.82	22.5	10.8	2.86	26.3	185	
7 years	Middle	Middle	2382	593.1	24.9	12.0	2.68	22.3	10.4	2.59	24.8	198	55
		Inner	2380	579.6	24.4	12.0	2.74	22.9	10.3	2.71	26.2	199	
	Top	Outer	2208	526.8	23.9	12.0	2.74	22.8	10.5	2.68	25.6	184	
		Middle	2137	464.7	21.8	13.2	2.99	22.7	11.6	2.94	25.3	162	
		Inner	2136	472.8	22.1	12.0	2.52	21.0	10.3	2.35	22.8	178	

Fig. 1. Change of fiber length of Ph. pubescens of the different age to the various height and part.

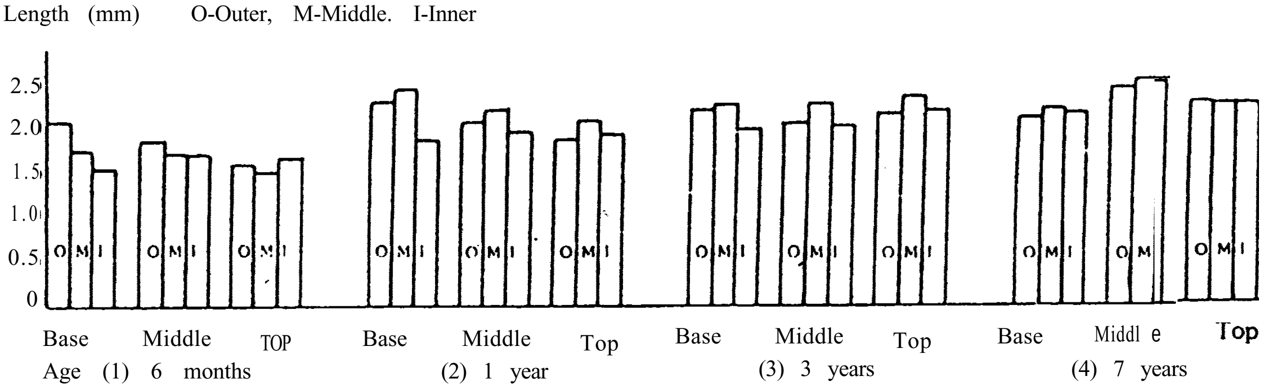
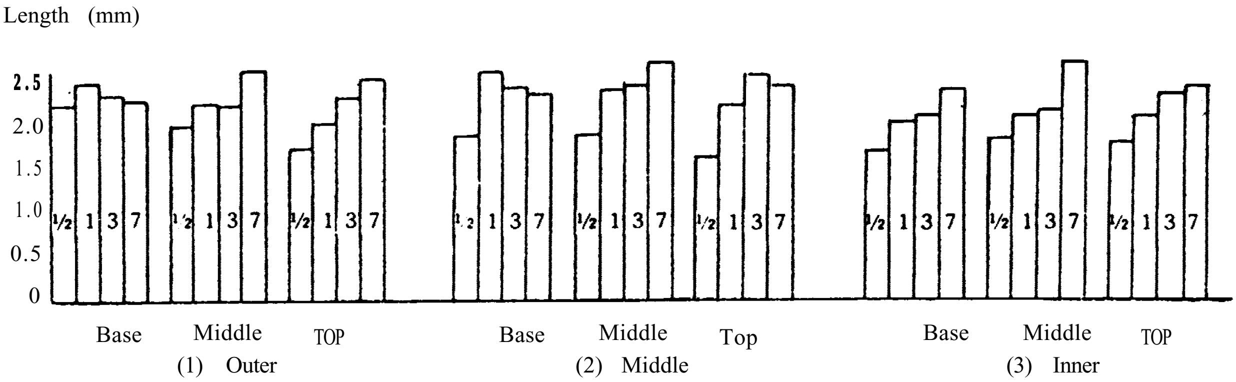


Fig. 2. Change of fiber length of Ph. pubescens of the same part at different ages.



The Mechanical Properties of Bamboo

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Abstract

Bamboo is compared with steel, concrete and timber in terms of the energy needed for production, safety, strength and stiffness as well as simpleness of production as a construction material. The outcome of the comparison places bamboo well ahead for construction purposes.

Introduction

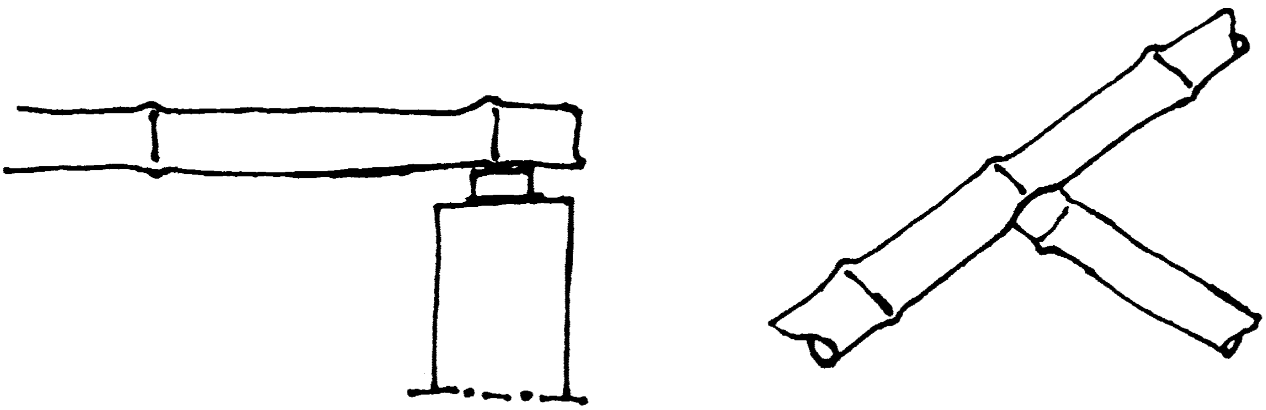
Bamboo cornpares well and favourably with other building materials like steel, concrete and timber over energy requirements during construction, strength and stiffness per unit area of material, ease and safety of use. To a great extent the versatility of bamboo is largely due to its anatomical structure which contributes to its mechanical properties.

1. The anatomy and the properties of bamboo:

Bamboo has promising mechanical properties, To understand this it is important to study its anatomical and morphological characteristics. In a circular cross-section bamboo is hollow. For structural uses this form has many advantages in comparison to a massive and rectangular cross-section (e.g. wood). Bamboo needs only 57% material when used for beam, and only 40% when used as a column. However, because of its tapered form bamboo is not viewed with favour by engineers – as the tapering causes a strength loss between 35-40%. In building structures beams and columns with the same strength along the full length are needed. But on careful examination this fact seems to be exaggerated because bamboo retains much of its strength in spite of the taper by the manner in which vessels and materials are distributed from top to bottom, e.g. a quarter sclerenchyma tissue more at the top than in the bottom of the culm (32% in the bottom, 41% at the top).

In the final analysis, there may be a total loss of about 15% only. The disadvantage does not disappear, but its influence is much less than many people fear.

The next factors affecting mechanical properties are the nodes and the diaphragms of the culm. These have a structural function in support, especially when two culms join together (Fig. 1).



At internodes the structure seems weaker. But the influence of diaphragms on the bending behaviour is still unknown. In Eindhoven we have carried out bending tests on full culms with and without diaphragms. The detailed analysis is still being carried out — the first impression shows no significant differences.

The outer skin of bamboo has a considerable amount of silica. It improves the natural durability but preliminary studies indicate that the mechanical strength of the culm is not tignificantly affected by its absence.

Bamboo is a composite. In mechanics a composite is a material composed of soft and weak material, stiff and strong material, In bamboo the former is cellulose and the latter lignin.

Other well known examples are reinforced concrete and glass fibre polyester. In materials-science composites are well known for their good properties, the properties of the whole being better than the sum of the component parts. The distribution of the cellulose in the cross-section of the wall of a culm contributes to the quality of strength of the material. On the outside the percentage of cellulose is as much as 60%, decreasing to a 20% on the inside. From a mechanical point of view the material on the outside is far more effective. As a result, the strength and stiffness of a bamboo culm is better than in a case where cellulose is distributed equally. Though the chemical composition of wood and bamboo do not differ very much, bamboo is twice as good in stiffness than wood. The reason for this is not known yet; the best hypothesis is the angle between the cellulose microfibrils and the cell-axis, being 20^0 for wood and only 10^0 for bamboo. Bamboo does not have any rays. A ray is a weak spot, because it serves transport and storage of food. As a result, bamboo is far better in shear than wood, contrary to the general opinion. This last statement, however, is based on the thickness: 6 or 7 mm is normal for bamboo, but unheard of for wood.

2. The advantages of bamboo as a building material:

How does bamboo compare with three other common building materials: concrete, steel and timber? Evidently, such a comparison can only be rough and difficult as well, because each of these four consists a number of different variables. Given in the subsequent paragraphs are four factors for which comparisons are made. These are:

a. The energy needed for production: Energy has to be expended to produce any material, In the case of fabricating structural elements for the construction industry energy has to be used to produce a beam or column. One can measure the benefit of prodycing a column with different materials by working out amounts of energy needed to handle a certain amount of load. The energy needed for four constructing materials is given below in the table.

Table 1. Energy needed for production compared with stress when in use.

Material (1)	Energy for production MJ/kg (2)	Weight per volume kg/m³ (3)	Energy for production MJ/m³ (4)	Stress when in use N/mm² (5)	Ratio energy per unit stress (4)/(5)
Concrete	0.8	2,400	1,920	8	240
Steel	30	7,800	234.000	160	1.500
Wood	1.	600	600	7.5	80
Bamboo	0.5	600	300	12	25

Energy, needed for production, compared with stress when in use.

In column (2) data about energy is given which can be found in several handbooks on materials technology. The energy for wood deals with logging, sawing and transport, and the energy for bamboo with harvesting and transport only. Columns (3) and (4) are needed to obtain data on energy per volume, to be compared with the stresses in column (5). The result, the ratio between the energy for production and the stress in the material, is given in column (6).

It is seen from the last column that per equal unit of load bearing capacity, bamboo requires the least energy for its production. Timber is the second, reinforced concrete the third, and steel requires the most. These figures are not exact, they give only an order of magnitude. We can see, however, that steel and concrete make a heavy demand on a large part of the energy resources of the "missile" earth, contrary to wood and bamboo.

In fact, this table should be enlarged with the lifetime of the materials concerned, but then the energy demand of the several methods of preservation should be added as well.

Due to the fact that the energy in the production process is an important component of the price, it is tempting to state that bamboo is a very cheap building material, however this assumption is too simplistic and the temptation has to be avoided.

b. *The safety* of *the* material: Bamboo is considered generally a safe building material. Its capacity to survive an earthquake or a hurricane is well known. This capacity can be related to two mechanical properties.

i. The strain energy, i.e. the energy stored into the material during load bearing. The strain energy is defined as the surface of the stress-strain-diagram

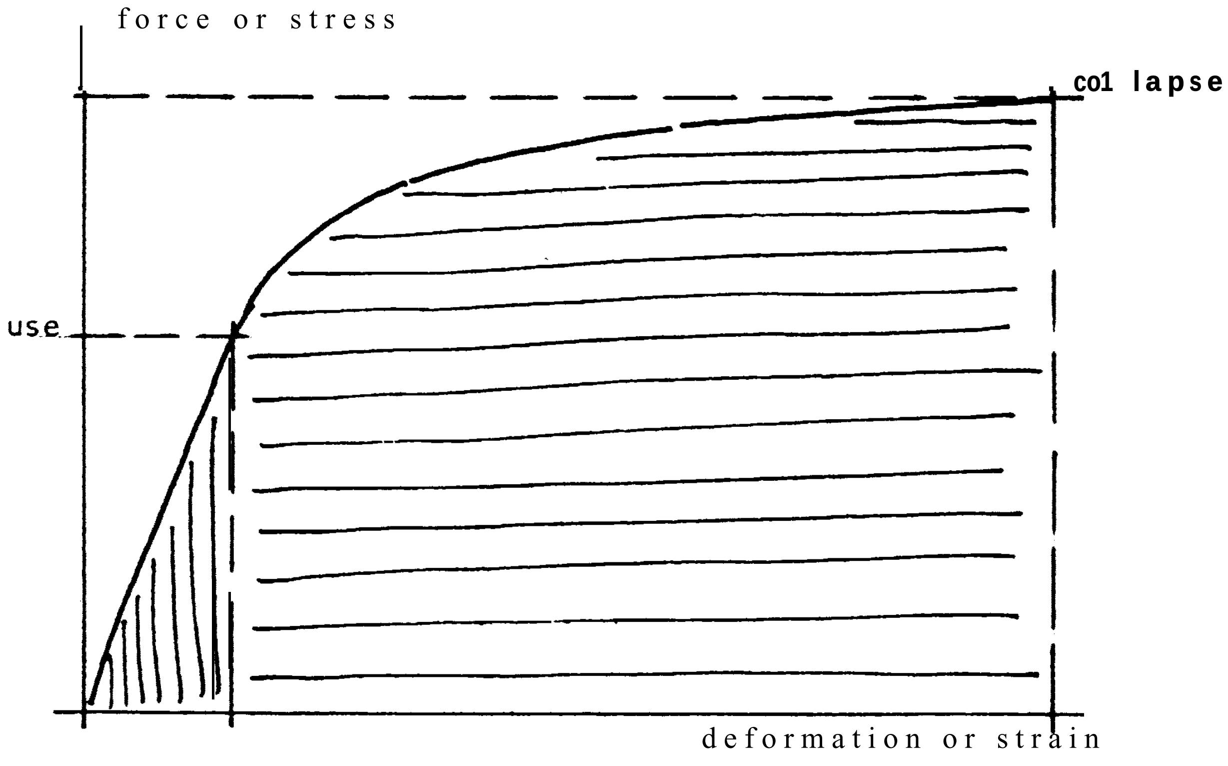


Fig. 2 Stress-strain diagram

A test on building materials results in a diagram, representing the relationship between the force, acting on the material, and the deformation of the material. The surface below this diagram represents the energy, 'stored in the material. (Fig.2)

The area, shaded vertically, represents the situation of a normal use of the material in a building,while the area,shaded horizontally, represents the situatjon of a collapse. Evidently, the ratio between the two areas is an estimation for the safety of the material. Calculations of this ratio show:

concrete	10
steel	1400
wood	20
bamboo	50

This means that from a safety point of view, steel is safest, bamboo second, wood the third and concrete last.

ii. A -second property deals with the deviation in the strength. Deviation means: when testing a building material, some specimens will behave very well, while others behave worse. The test results appear to be scattered around the mean value. In the case of steel, a well-controlled product, this scattering is very small and the allowable stress o can be about 60 percent of the mean strength om:

And the behaviour of concrete is in between these.

On the contrary, in the case of naturally grown products like wood and bamboo, the scattering is very wide, and consequently (to avoid the use of a bad specimen in a building) the allowable stress 'o', is only a 15 percent of the mean Strength °m:

During an earthquake,cyclone,or any similar disaster, the stress in any building will increase, leaving from 'o', being the normal situation. In the above diagrams it can be seen that steel will collapse rather quickly, followed by concrete, with wood and bamboo in the last (and best!) place.

c. The strength and the stiffness per unit of material: In construction the strength and stiffness of a material is important. This can be measured by calculating the ratio between allowable stress and the mass per volume. Given below are figures for:

concrete	0.003
steel	0.020
wood	0.013
bamboo	0.017

in which bamboo appears to be the best one with respect to strength.

As to stiffness, the ratio between the Young's modulus and the mass per volume is used. (Figs. 3-5)

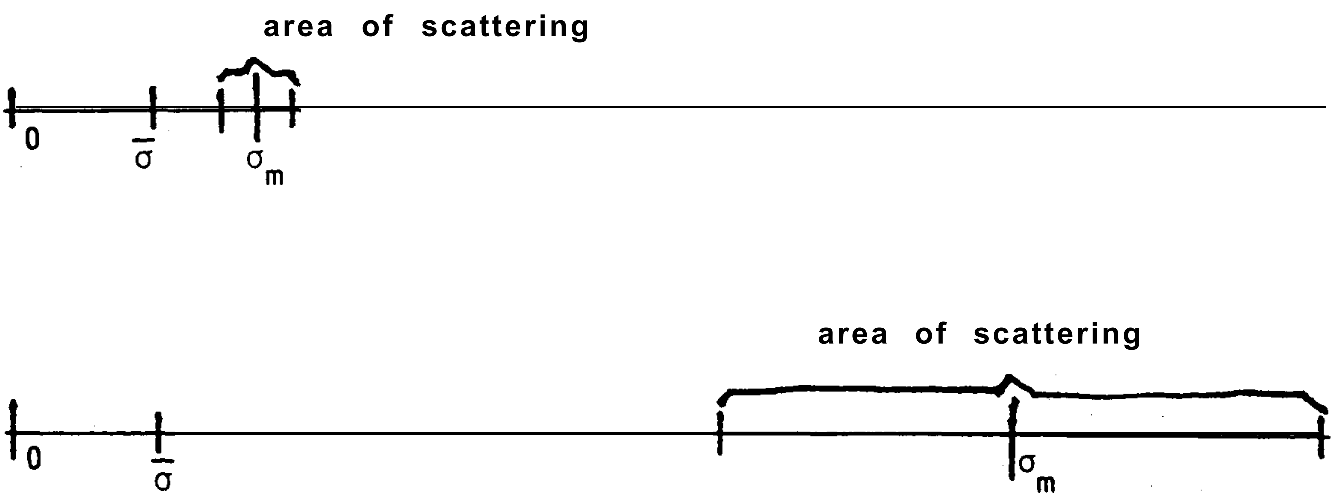


Fig. 3. Strength tests on (a) steel and (b) wood and bamboo

Taking all four together:

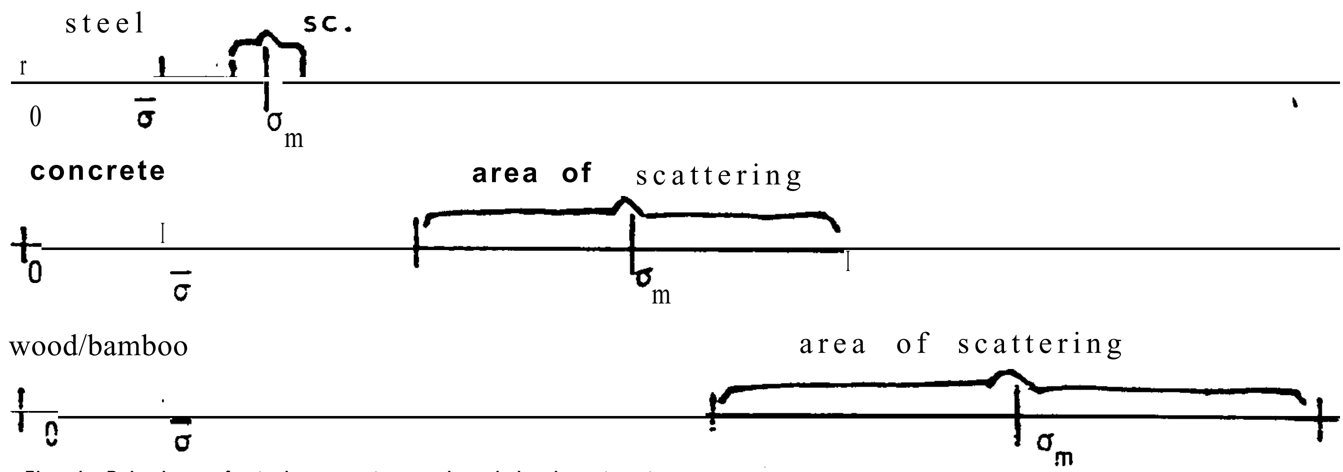


Fig. 4. Behaviour of steel, concrete wood and bamboo to stress.

concrete	10
steel	27
wood	18
bamboo	33

from which bamboo appears to be the best.

d. The simpleness of production: This aspect seems to be more "soft" than the three mentioned ahead; for the people who use bamboo, however, it is as important.

a. Building with steel and concrete does not belong to the normal possibilities for village people, in contradiction to wood and bamboo. However, in the case of wood one has to wait many years, but in the case of bamboo one can harvest the ripe culms each year.

b. An environmental advantage: in the case of wood a whole area is cut at once, but in the case of bamboo only the ripe culms are cut, while the younger culms (the majority!) are left. For the micro-climate and the environment this yearly partial crop is much better.

c. Due to its circular and hollow shape, only simple tools are needed for its cropping and use. With bamboo there is no sawing or logging like in the case of wood; waste material like bark and sawdust is unheard of.

d Bamboo is represented by many botanical species, each with its own properties. As a result one can find an appropriate bamboo for a variety of purposes.

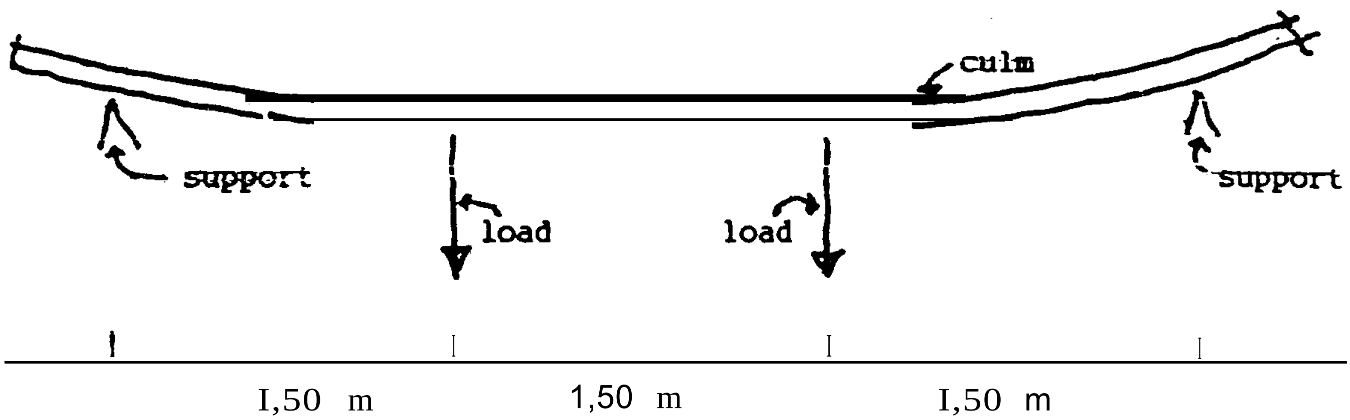


Fig. 5. Bending of bamboo Culm

3. The long term behaviour of bamboo under load:

Laboratory tests on the mechanical properties of bamboo are usually short-term tests. Building, however, is a long-term activity, and consequently we need long-term tests to learn about the long-term behaviour. Such tests have been carried out in the Eindhoven Bamboo Laboratory for the past three years (1982 – 1985). Tests have been carried out concerning the bending of bamboo culms, as follows:

Bambusa blumeana from the Philippines was obtained for the study and factors like

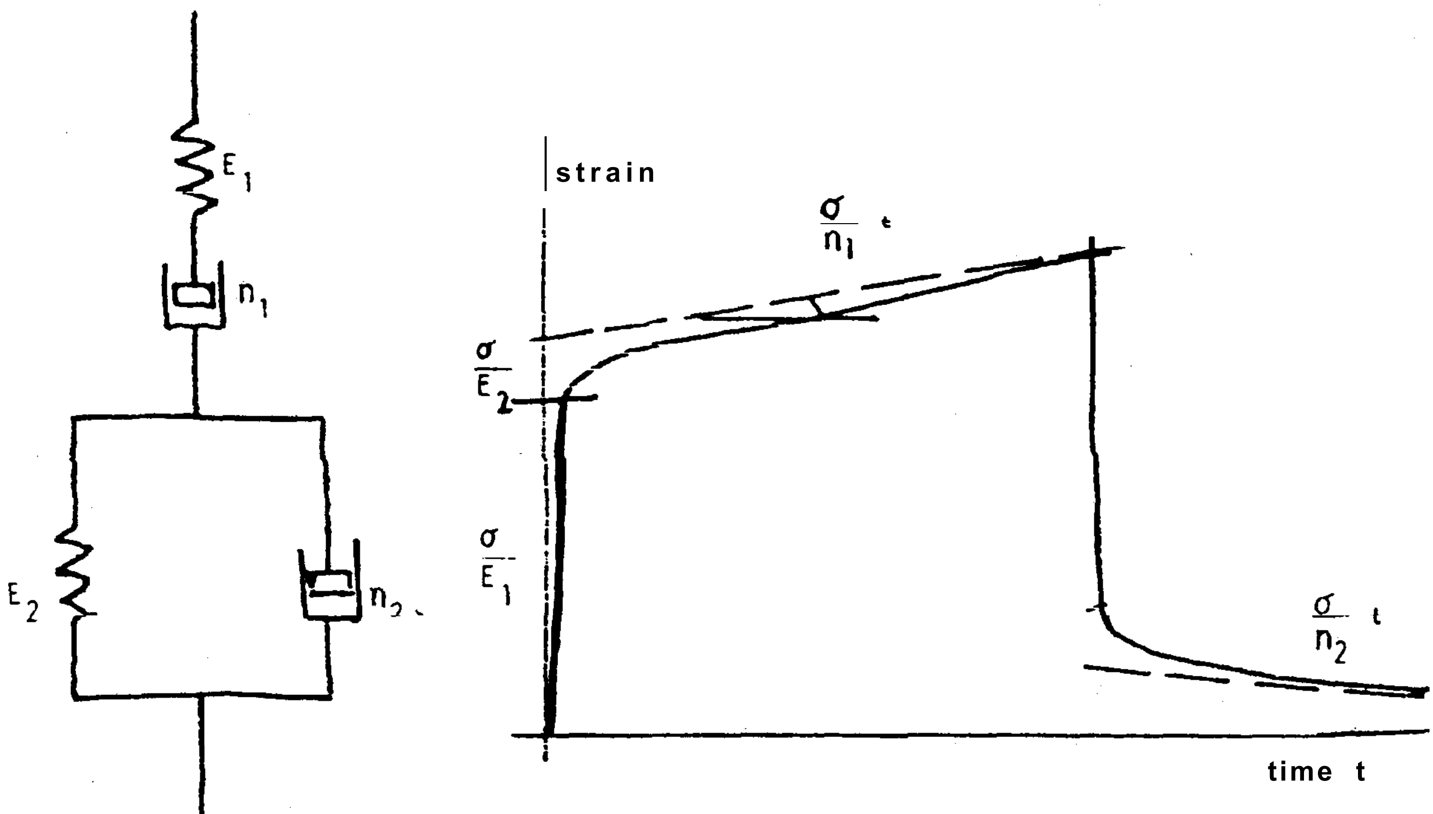


Fig. 6a & b. Creep and recovery using Burgers-model.

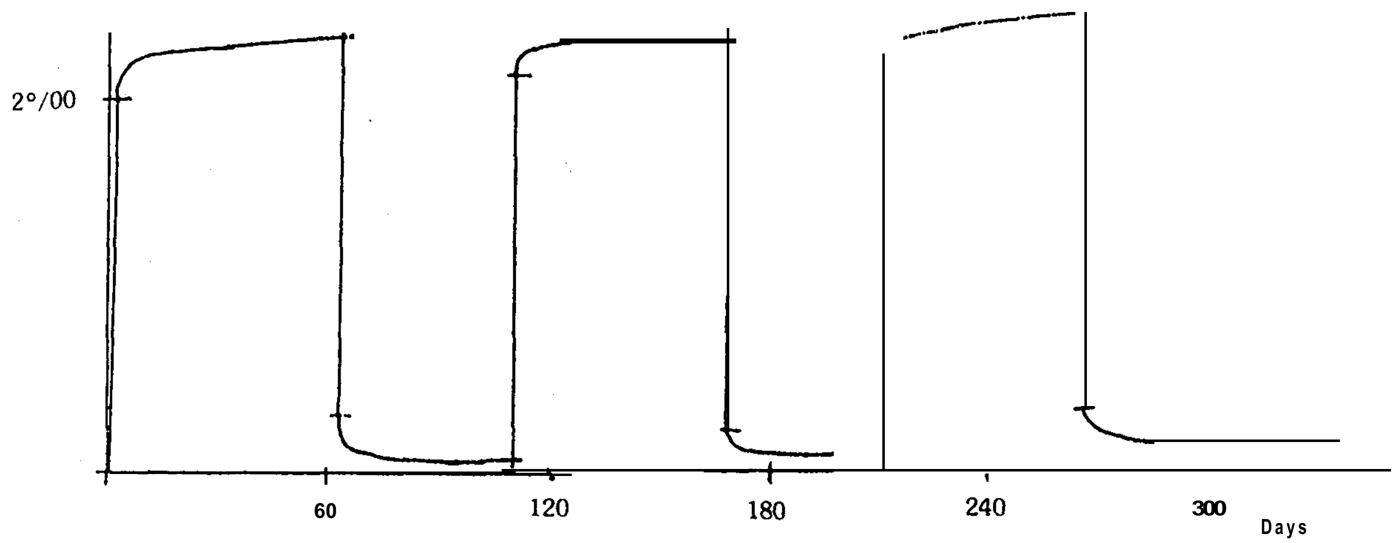


Fig. 7. Creep deformation

diameter, thickness of wall, mass per volume, fibre content and the angle between microfibrils and cell axis were taken into account. Samples were subjected to the test with and without diapraghms and outer skin with an m.c. of 8 and 12% with the ambient RH at 60 or 80%.

The load was applied in such a way that the initial strain was 2 pro mille. Creep and recovery were studied during eight to six weeks each and this was carried out four times. Unfortunately, the analysis has not been completed and preliminary trends can be seen. (Figs. 6. 7)

Firstly: creep and recovery in bamboo can be described with a Burgers-model, as follows:

in which:

6 is the applied stress, kept constant.

6/El is the immediate deformation, the immediate strain; the cellulose acting as a spring; this strain is elastic, it disappears with the load; it happens in the crystalline part of the cellulose.

6/E2 is the creep, the increase of strain with time.

nl is a viscous component, symbolized as a dashpot; it is a plastic deformation caused by a sliding between cellulose chains in the amorphous part of the cellulose, and by a deformation in the amorphous lignin; this strain disappears with the load.

m is the permanent deformation, remaining after removal of the load.

The use of this mathematical model is to calculate the said E's and n's as physical properties.

Secondly, the deformation which remains after removal of the load, is for bamboo only 5 to 10 percent of the immediate deformation, to be compared with 50 to 100 percent in the case of wood. For practical purposes this is wonderful; detailed analysis has to be done to test the data for scientific rigour.

Physico-Mechanical Properties and Anatomical Relationships of Some Philippine Bamboos

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Abstract

This report includes the physico-mechanical properties and anatomical characters of Bambusa blumeana and Gigantochloa levis. Physico-mechanical properties such as relative density, shrinkage, moisture content, static bending and compression parallel to the grain were correlated to anatomical characteristics, e.g., fibrovascular bundle frequency and dimensions of fiber and vessel. Results showed that there is an increase in compressive and bending strengths towards the top portion of the culm of both species. This trend could be attributed to the significant increases in relative density and fibrovascular bundle frequency.

Introduction

Housing is one of the basic needs of man. The pressures of population on the dwindling supply of commonly used timbers for housing calls for research and development efforts on the use of non-timber forest products, particularly bamboo. Certain aspects of the properties and use of these resources have been neglected. If studied, the results may help the efficient use of bamboo materials for housing components.

A knowledge of the physical and mechanical properties in relation to the anatomical characteristics of erect bamboo is necessary in assessing its potential uses as building material for housing, furniture making and for general construction work and in converting it to a variety of finished products. Furthermore, the different properties of this resource will not only serve as a basis for promoting its acceptance but also for improving its market potential.

Several studies on characteristics and properties of *B. blumeana* and G. levis were undertaken (Tamolang et al., 1980). Velasquez and Santos (1931) studied five species of bamboos and claimed that *B. blumeana* was one of the most common and widely distributed bamboos in the Philippines, occurring in cultivation throughout settled areas at low altitudes.

B. blumeana was purposely introduced from Malaysia during pre-historic times (Merrill, 1916). It is, by far, the most valuable and popular species of bamboo used for construction in rural areas. The stem of B. *blumeana* consists of a hollow culm with distinct nodes and internodes. It grows from 10 to 25 m high and reaches a diameter of 80 to 150 mm. It is erect, nearly straight from the base'upward and gently bending ata the top. The basal portion of the clump is surrounded by a dense thicket, 2 to 3 m high, of spiny branches.

On the other hand, G. *levis* may be considered as an exotic species (Merrill, 1916). It grows in certain areas of the Philippines and also in dense forests, especially in moist places in ravines or depressions near streams. Its general appearance resembles that of B. *blumeana* although its culm is stout, straight and smooth with very much less prominent nodes than *B. blumeana.* It reaches a height of 10 to 25 m and a diameter of 100 to 200 mm. Brown and Fischer (1918) said that the stems of this bamboo species are only used as pipes for temporary water supply and for building fish traps; rarely used for building operations, except for walls of houses, because they are especially durable.

Bamboos, in general, belong to the Barn-. buseae tribe of the huge family Gramineae (Sineath et al., 1953)) characterized by hollow or rarely solid stems that are closed at the joints or nodes. The anatomical structure of the two species considered in this report were studied (Velasquez and Santos, 1931; Grosser and Zamuco, 1971; Zamuco and Tongacan, 1973). The compact fiber tissues are present in the outer part of the culm, whereas the inner part is mostly of parenchyma cells. A study of B. blumeana (Espinosa, 1930) showed that for all engineering purposes, a culm about 300 mm in circumference, when loaded at the center on a span of 1.52 m can support 500 kilograms weight. When used as a post or column of about 1.22 m, it can support 4,000 kg.

Espiloy (1979, 1983) studied the variability of specific gravity, silica content and fiber measurements in B. blumeana; a strong positive correlation was found to exist between specific gravity and cell wall thickness and silica content. The anatomical structure of the bamboo culm is the basis for understanding the physical properties of bamboo, and is responsible for specific gravity, silica content and fiber dimension to vary across and along the bamboo culm.

The chemical properties and eating qualities of shoots of three ages (7, 10 and 15 days after emergence) of B blumeana, G. leuis and four other species were studied (Gonzales and Apostol, 1978). Chemical analysis of the nutrient components showed that age level had no effect on nutrient content. Results of a taste test disclosed that 15 day-old B. blumeana shoots were the most acceptable as far as colour, texture and taste are concerned.

Escolano et al. (1964) found B. blumeana suitable for pulp and paper making and that this species yields good quality bond, airmail bond, onion skin, offset book, kraft, wrapping and bag papers. Likewise, Semana (1967) found the same species to be a suitable raw material for kraft pulps due to its pulp strength, pulp yield and acceptable level of silica content.

Bamboos. are very susceptible to the attack of decay fungi and powder-post beetles, particularly Dinoderus minutus Fabr. (Casin and Mosteiro, 1970). The presence of starch in bamboo contributes to its susceptibility to beetle attack (Liese, 1980). A tentative classification showing the natural resistance of some bamboo species to fungal attack was made (de Guzman, 1978), based mostly on percentage weight loss of specimens after four months of exposure. B. blumeana and G. *leuis* were considered moderately resistant.

Present Studies: In the present studies, the author determined the effect of fibrovascular bundle frequency, culm, wall thickness, diameter and length or span of material on the different physical and mechanical properties along the culm length. The interrelationships of the different physical and mechanical properties in relation to their anatomical characteristics within and between species were also evaluated to ascertain their suitability for various uses, especially in housing.

Five culms each of three-year old B. blumeana and G. leuis were used in this study. The culm length, diameter, length and number of internodes per culm were recorded. Representative sections of the butt, middle and top portions were cut into segments comprising of eight whole-length internodes. The segments and internodal sections were number-coded to indicate their original positions in the culm. Each eight-internodal section was further cut for use in the different tests. In general, the standard test procedure of the American Society for Testing Materials for small clear specimens of timber was followed for determination of physical and mechanical properties. The data obtained are the average properties of the material in green condition. The frequency of fibrovascular bundles per unit area was determined directly using a calibrated magnifier, "Scale lope" at 20 x magnification. The length, width, lumen diameter and cell wall thickness of fibers and vessel length and diameter were determined,

Physical and Mechanical Properties: Culm height, number of internodes per culm, length and diameter of internodes, and culm wall thickness of Bambusa blumeana and Gigantochloa leuis are presented in Table 1. *B. blumeana* has longer and more internodes per culm and thicker culm walls than G. leuis; the latter is taller and the diameter of its internodes is bigger than the former. The average

Table 1. Physical data forculms of B. blumeona **and G.** leuis **collected in Bayog,** Los **Banos. Laguna and Nagcarlan, Laguna, respectively.**

Property	Species	
	B. blumeana (Kauayan-tinik)	G. leuis (Bolo)
1. Culm height (m)	i2.9	14.9
2. Number of internodes per culm	40.0	36.7
3. Internode length (mm)		
a) Butt	284.00	200.4
b) Middle	432.7	455.4
c) Top	321.0	264.8
Average	345.9	306.9
4. Internode diameter (mm)		
a) Butt	101.4	121.2
b) Middle	80.5	94.1
c) TOP	41.0	40.0
Average	74.3	85.1
5. Culm wall thickness (mm)		
a) Butt	19.4	12.2
b) Middle	9.1	8.7
c) TOP	6.3	5.8
Average	11.6	8.9

Table 2. Average physical and mechanical properties of **B.** blumeana **and G.. leuis.**

Property	Species							
	B. *blumeano* (kauayan-tinik)				G. levis (Bole)			
	Butt	Middle	Top	Average	Butt	Middle	TOP	Average
1. Moisture Content (%)	194.7	114.0	98.8	135.8	143.0	115.1	93.8	117.3
2. Relative Density'	0.388	0.537	0.585	0.503	0.474	0.539	0.610	0.541
3. Shrinkage (%)								
a) Thickness	16.6	13.3	10.0	13.3	12.9	11.3	8.9	11.0
b) Width	12.0	6.2	4.8	7.7	8.0	6.5	5.2	6.6
4. Compression Parallel to Grain. Maximum crushing strength (MPa)								
a) Nodal	34.7	37.2	37.3	36.4	37.7	41.9	44.3	41.3
b) Internodal	35.9	39.5	39.5	38.3	38.7	41.7	43.4	41.3
5. Static Bending'								
a) Stress at proportional limit (MPa)	29.5	20.2	18.2	22.6	17.6	14.9	18.6	17.0
b) Modulus of rupture (MPa)	43.2	28.4	24.7	32.1	25.4	19.6	26.1	23.7
c) Modulus of elasticity (1000 MPa)	8.9	8.8	9.2	9.0	8.9	10.4	11.0	10.1

Based on volume at test and weight when oven-dry
• From green to oven-dry condition
Tested at green condition.

results of the different physical and mechanical properties of the two bamboo species are given in Table 2. The summary of analyses of variance based on the mean squares and statistical significance of physical and mechanical properties of the two species is shown in

Table 3. Summary of analyses of variance on physical and mechanical properties of B. blumeana and G. levis.

Source of Variation	Mean Squares and Statistical Significance							
	Physical Properties				Mechanical Properties			
			Shrinkage			Static Bending		
	Moisture Content	Relative Density	Thickness	Width	Compression parallel to grain (maximum crushing strength)	Stress at Proportional limit (SPL)	Modulus of rupture (MOR)	Modulus of elasticity (MOE)
Treatment (Butt. Mid, Top)	51129.90'	0.3321'	243.09'	239.38'	5443.019"	10884.936 ns	32240.700 ns	300.237"'
Block (species)	13038.32 ns	0.0300 ns	196.86 ns	45.88"'	24040.017"	24741.482"'	55126.533"'	908.900 ns
cv (X) %	63.88	29.60	68.50	80.12	3.97	48.67	54.35	17.26

- Significant at 95% level of probability
- Significant at 99% level of probability

ns Not significar

Table 3.

For both species, moisture content and shrinkages on thickness and width decreased towards the top while their relative density values increased towards the top. Results show that there is a significant difference in all the physical property values investigated at three height levels but none between species. There was a general trend of increasing maximum crushing strength (MCS) values from butt to top portions which was found highly significant at three height levels and between species. On the other hand, there was no distinct trend in bending properties, i.e., stress at proportional limit (SPL), modulus of rupture (MOR), and modulus of elasticity (MOE) although most of the highest strength values were observed at the top portions. However, such differences in bending properties at three height levels and between species were found insignificant. As in wood (Heck, 1956) the strength properties in bending of bamboo are correlated with specific gravity or relative density.

Anatomical Properties and Characteristics: Some anatomical properties and characteristics of the two species which include frequency of fibrovascular bundles and dimensions of fibers and vessels are shown in Table 4. B. blumeana averaged higher than G. *leuis* in fibrovascular bundle frequency, but their respective values increased from the butt towards the top portion. G. *leuis* averaged higher than B. blumeana in all vessel and fiber dimensions, except for fiber length. A summary of analyses of variance based on

Table 4. Some anatomical properties and characteristics of blumeana and G. leuis.

Property	Species							
	B. blumeona (kauayan-tinik)				G. levis (Bolo)			
	Bun	Middle	Top	Average	Butt	Middle	Top	Average
1. Fibrovascular bundle frequency (No. per sq. mm)	1.74	3.12	3.80	2.89	1.11	1.50	2 06	1.56
2. Fiber dimensions (mm)								
a) Fiber length	2.50	2.55	2.63	2.56	1.88	1.52	2.05	1 82
b) Fiber diameter	0.0148	0.0152	0.0142	0.0147	0.0165	0.0155	0.0159	0 0160
c) Lumen diameter	0.0046	0.0032	0.0034	0.0037	0.0056	00036	0.0065	0.0052
d) Cell wall thickness	0.0052	0.0061	0.0054	0.0056	0.0060	0.0058	0.0059	0.0059
3. Vessel dimensions (mm)								
a) Vessel length	0.8228	0.7068	0.8294	0.7863	1.1305	0.6776	0 5957	0.8013
b) Vessel diameter	0.1862	0.1366	0.1736	0.1655	0.2310	0.2308	0.1989	0.2202

Table 5. Summary of analyses of variance on some anatomical properties and characteristics of B. blumeana and G. levis.

Source of Variation	Mean Squares and Statistical Significance						
		Fiber dimensions				Vessel dimensions	
	Fibrovascular bundle frequency	Fiber length	Fiber diameter	Lumen diameter	Cell wall thickness	Vessel length	Vessel diameter
Treatment (Butt. Middle, Top)	179.681”	0.238^{ns}	3.22g^{ns}	19 769’	' 0.420’	1496.542”	43.972^{ns}
Block (Species)	837.801”	4.019”	43.471”	17.170”	6.914”	4945.081”	1314.614”
cv (X) %	56.55	14.49	26.85	38.09	5.49	20.64	24.33

ns — Not significant

' * — Significant at 99% level of probability

mean squares and statistical significance of their anatomical properties and characteristics is shown in Table 5.

Results show that differences in fibrovascular bundle frequencies at three height levels and between species were found highly significant. Likewise, almost all fiber and vessel characteristics and properties between species and in three height levels were found highly significant except for length and diameter of fiber and diameter of vessel (Table 4).

Correlation of Physical and Mechanical Properties with Anatomical Structure: The physical and mechanical properties of the two species which were correlated with their respective anatomical structure are shown in Tables 6 and 7.

Table 6. Correlation coefficients of different physical and mechanical properties with some anatomical structure of B. blumeana.

	Fibrovascular bundle frequency	Fiber length	Fiber diameter	Lumen diameter	Cell wall thickness	Vessel length	Vessel diameter
Moisture content	0.035	0.2%	0.290	0.347	0.035	- .014	0.025
Relative density	-0.017	- 0.272	-0.186	- 0.331	0.111	0.363	0.463
Shrinkage (thickness)	-0.182	-0.162	-0.126	-0.268	0.079	- 0.059	- 0.010
Shrinkage (width)	-0.633’	-0.193	0.003	- 0.208	0.188	0.072	0.025
Maximum crushing strength	0.121	- 0.310	-0.181	-0.262	- 0.060	10.103	0.307
Stress at proportional limit	0.063	0.535’	0.517	0.492	0.243	0.188	-0.003
Modulus of rupture	0.121	0.468	0.417	0.417	0.154	0.317	-0.221
Modulus of elasticity	0.716’	-0.177	0.043	-0.067	-0.130	-0.068	-0.256

* Significant at 95% level of probability

Table 7. Correlation coefficients of different physical and mechanical properties with some anatomical structure of G. levis.

	Fibrovascular bundle frequency	Fiber length	Fiber diameter	Lumen diameter	Cell wall thickness	Vessel length	Vessel diameter
Moisture content	-0.170	-0.130	0.080	0.310	-0.100	0.230	0.320
Relative density	0.110	0.180	- 0.080	- 0.260	-0.080	-0.18	-0.270
Shrinkage (thickness)	- 0.366	0.095	0.011	-0.027	0.110	0.446	0.154
Shrinkage (width)	-0.528’	0.131	0.199	0.217	0.023	0.366	0.219
Maximum crushing strength	0.020	0.270	0.060	- 0.810’	0.170	-0.480	-0.280
Stress at proportional limit	-0.530’	-0.810’	0.420	0.490	-0.100	- 0.245	0.240
Modulus of rupture	-0.510’	- 0.220	0.250	0.460	-0.103	- 0.230	0.290
Modulus of elasticity	- 0.080	-0.090	0.160	0.130	0.004	-0.130	- 0.003

. Significant at 95% level of probability

Table 8. Correlation coefficients of physical characteristics of specimens with compressive and bending properties ofB. blumeona and G. leuis.

	B blumeana (Kauayan-tinik)						G levis IBolo)					
	Comprerssion parallel to grain		Static bending				Compression parallel to grain		Static bending			
Physical Characteristics of Specimen	Maximum crushing strength	Relative density	Stress at proportional limit	Modulus of rupture	Modulus of elasticity	Relative density	Maximum crushing strength	Relative density	Stress at proportion- al limit	Modulus of rupture	Modulus of elasticity	Relative density
Outside diameter	-0.230	-0.208	0.081	0.081	-0.260	-0.293	-0448'	-0434'	-0 124	-0.230	-0363	-0.789'
Length/Span	-0.290	-0.436	0.081	0.080	-0.261	-0.293	-0668'	-0.441'	-0.125	-0.230	-0.362	-0.790.
Culm wall thickness	-0.290	-0.436'	0.617'	-670*	-0 175	-0462	-0.668'	-0.441*	-0.120	-0.163	-0.795'	-0615'

'Significant at 95% level of probability

In B. blumeona (Table 6), fibrovascular bundle frequency is negatively correlated with shrinkage on width of specimens (r = – 0.528*), stress at proportional limit (r = -0.530*), and modulus of rupture (r = -0.510'). This means that an increase in fibrovascular bundle frequency towards the top portion of the culm may result in decreased shrinkage on width, stress at proportional limit and modulus of rupture values, as can be seen in Table 2.

There was also a negative correlation between stress at proportional limit and fiber length (r = -0.810') and between maximum crushing strength with lumen diameter (r = -0.810'). This implies that decreased stress at proportional limit towards the top portion may be due to increased fiber length and that an increased maximum crushing strength towards the top may' be due to decreased lumen diameter resulting in thicker walls, as can be seen in Tables 2 and 4.

On the other hand, the fibrovascular bundle frequency in G. leuis (Table 7) was also negatively correlated with shrinkage on width (r = -0.633') of specimens but positively correlated with modulus of elasticity (r = 0.716'). Stress at proportional limit was also positively correlated with fiber length (r = 0.535'). This implies that the increased modulus of elasticity towards the top portion is due to the increased fibrovascular bundle frequency where decreased shrinkage also occurred. The length of fiber has something to do with the increased values in stress at proportional limit towards the top portion of the culm, as seen in Tables 2 and 4.

Correlation of Physical Characteristics of Specimens with Compressive and Bending Properties: Table 8 shows the correlation of outside diameter, length or span and culm wall thickness of specimens with compressive and bending properties of the two species. In B. blumeano, the length or span and culm wall thickness with same values of (r = – 0.436') were negatively correlated with relative density in compression whereas the culm wall thickness was positively correlated with bending properties such as stress at proportional limit (r = 0.617') and modulus of rupture (r = 0.670'). This means that as the culm wall thickness decreases towards the top, there is a corresponding decrease in stress at proportional limit and modulus of rupture where increased relative density also occurred (Table 2).

In G. leuis, the outside diameter, length or span and culm wall thickness of specimens were negatively correlated with maximum crushing strength and relative densities both in compressive and bending properties. Likewise, there was also a negative correlation between culm wall thickness and modulus of elasticity (r = -0.795'). This implies that a decrease in any of the physical characteristics of specimens may result in a corresponding increase in relative density and maximum crushing strength of the materials (Table 2).

Conclusions and Recommendations

This study has disclosed some interesting facts regarding the different properties of B. blumeana and G. leuis.

Based from test results, *B. blumeana* was found to have a considerably lower relative density than G. *levis* which is associated with higher moisture content and shrinkage values. G. *levis* was found to have a higher maximum crushing strength than the former but was weaker in bending strengths, except for modulus of elasticity.

With regard to their anatomical structure, *B. blumeana* averaged higher than G. *levis* in fibrovascular bundle frequency but lower in all fiber and vessel dimensions, except for fiber length. Anatomically, relative density is regarded as a function of the ratio of cell wall volume to cell void volume. As such, it is affected by cell wall thickness and structure, cell width, the relative proportions of different types of cells, and the kind and amount of extractives present. Moreover, relative density is a measure of the strength properties of a material. The findings of other investigators were verified in this study. The general increase in compressive and bending strengths towards the top portion of the whole culm could be attributed to the significant increases in relative density and fibrovascular bundle frequency towards the same direction along the culm length.

Similar studies on other bamboo species should be undertaken. Further investigation is necessary to confirm these findings, which at this point can be considered preliminary. The findings must be interpreted with caution, since the results may not hold true for other bamboo species growing in another site and subjected to varying environmental conditions.

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Diseases

Bamboo Blight in the Village Groves of Bangladesh

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Abstract

Bamboo blight is an important disease of village grown bamboo in Bangladesh. The blight first affects new culms but may also continue into older ones. The symptoms of the disease have been briefly described. **Coniothyrium fuckelii** Sac. and **Acremonium strictum** W. Gams are commonly isolated from blighted bamboo culms. The results of isolation of fungi and pathogenicity tests are presented. In the experiments performed **A. strictum** produces blight symptoms. Previously infected culms show a higher incidence of disease when compared to new culms which developed from healthy parent culms. pH of soil of bamboo clumps, carbon and nitrogen contents of bamboo culms are not associated with the development and severity of blight.

Various control measures have been attempted which range from improued cultural practices to field tests with fungicides. Dithane M 45 is able to reduce the amount of blight developing in culms. Remouing blighted bamboos, burning debris **in situ** and putting new soil in clumps significantly increased the survival of new culms.

Introduction

Bangladesh lies between 20.75° and 25.75° North Latitudes and 88.30° and 92.75° East Longitudes. It has an area of 143,997 square kilometres. The climate of Bangladesh is tropical. Summers are hot and wet, while the winters are cool and dry. The temperature varies from 52°F to 84°F in winter and 70°F to 94°F in summer. Total annual rainfall varies from 1,200 mm to 3,500 mm. Nearly 80 per cent of the annual rain falls between June and October. Humidity is generally high through most of the year raising to almost 90 per cent in the rainy season. Bamboo is an important economic crop in Bangladesh and of the 18 commercially useful species described by Alam (1982), three are specially important. They are Bambusa balcooa, B. Vulgaris and B. tulda.

Bamboo blight was first noticed in some parts of Rajshahi district. General information on the symptoms and isolation of fungi associated with blighted bamboo tissues have been reported by Rahman and Ole Zethner (1971), Gibson (1975) and Rahman (1978). The latter also provided a review of reported bamboo diseases. Pawsey (1980) included some historical background and importance of the problem. Boa and Rahman (1983) reported the history of bamboo blight and its epidemiology, described the disease and recorded its etiology and on the spread of the disease. Rahman and Khisha (1981) ascribed Acremonium strictum W. Gams as a pathogen which can cause bamboo blight. Rahman, Khisha and Basak (1983) reported on some of the factors relating to regeneration and mortality of two bamboo species. This paper reviews earlier findings and reports more recent work on bamboo blight.

Symptoms Of Bamboo Blight

Mortality of bamboos, particularly those in the village groves, mainly occur in two stages: i) mortality of very young emerging culms generally within heights of 40 cm, and ii) mortality of newly growing culms which attain heights of about 1 m to 5 m. The former type of mortality is very common (Rahman, Khisa and Basak, 1983; Banik, 1983) but the actual cause of mortality of emerging culms is not known. Banik (1983) has suggested that eco-physiological conditions and genetic make up of each species and clump seem to influence the rate of mortality of emerging culm in bamboo. Mortality of growing culms, generally within heights of l-5 m, is by far the most damaging. The death of the small emerging culms, start as a light brown to brown discolouration of culm and culm sheaths. Discolouration may start either at the top or near soil level or along any side of the emerging culm. With the advance of discolouration and decay, the culms fail to develop and ultimately rot and disintegrate. The symptoms of the blight of growing culms have been reported (Rahman, 1978: Rahman and Khisa, 1981). Boa and Rahman 1983) and is covered more thoroughly by Boa, 1985 (in this proceedings).

Isolation Of Fungi

Fungi were isolated from diseased Bambusa balcooa collected from Chapai Nawabganj in Rajshahi (in the western part of the country) and also from Forest Research Institute campus; and from *B.* vulgaris from Chittagong, on the eastern part of the country, on Potato sucrose Agar or 2% Malt Agar medium using standard phytopathological techniques. Isolations of fungi from B. balcooa were from diseased (i) culm sheaths (ii) young culms (iii) older culms (iv) young branches (v) leaf sheaths and from healthy branches and culms. Details of the results of isolation have been published elsewhere (Rahman, 1978; Rahman and Khisha, 1981). These isolations predominantly yielded Coniothyrium fuckelii Sac. But from blighted young branches and leaf sheaths of B. balcooa, and also from blighted older culms and young branches of B. vulgaris, Acremonium strictum W. Cams, was most dominantly present. C. fuckelii was also isolated from blighted older culms of B. oulgaris. Other isolates including Fusarium *monili*formae Sheld, F. equiseti (Corda) Sacc., Staehybotris bisbui (Sriniv.) Barron were isolated only to a lesser extent.

Pathogenecity Tests

Artificial inoculations with fungi C. fuckelii S. bisbvi. A. strictus and F. moniliformae were carried out on young culms of **B. balcooa** and *B.* Vulgaris. Inoculations were carried out with or without any artificial injury on the host. Spore suspension (S.S.) and artificially infected bamboo blocks (1.B.B.) were used as inocula for pathogenicity tests.

The data in Table 1 reveal that inoculation

Table 1. Results of artificial inoculation of Bambusa balcooa in Rajshahi by Coniothdum fuckelii. Stachvboris bisbvi and Fusarium moniliformae.

Inoculant	Inocula type	Part inoculated	Treatment replication		% infected	
					nodal bud	inter node
Coniothyium fuckelii	S.S.	culm sheath	Inoculated	— 40	3	0
			Control	— 20	0	0
	S.S.	nodal bud	Inoculated	22	50	50
			Control	— 9	33	22
	I.B.B.	internode	Inoculated	— 25	24	28
			Control	— 7	28	0
Stachybotris bisbvi	I.B.B.	nodal bud & internode	Inoculated	— 12	67	0
			Control	— 4	25	0
	S.S.	culm sheath	Inoculated	21	0	0
			Control	— 7	0	0
Fusarium moniliformae	S.S.	culm sheath	Inoculated	— 15	0	0
			Control	— 15	0	0

Table 2. Results of artificial inoculation of Bambusa balcooa and B. vulgaris in Chittagong by Acremonium stricturn •

Bamboo Species	State of growth of culms or branches	Treatment	No. of culms/ branches		Symptoms
			Inoculated	Infected	
B. balcooa	— Young branch from culm cutting in shade	Inoculation Control	13 13	10"' 1	Typical blight symptom
	— Young branch from culm cutting in the open	Inoculation Control	12 12	8' 0	Typical blight
B. vulgaris	— Young culm still covered with culm sheaths	Inoculation Control	25 25	13' 6	Typical blight symptom

' The data have been adapted from Rahman & Khisha (1981)

with either C. fuckelii. S. bisbui or F. moniliformoe did not show any significant infection as compared to the controls indicating that none of these fungi was a primary pathogen of bamboo blight.

Development of symptoms and resultant blight of young growing branches from ground layered culm cuttings of B. balcooa were severe when the host materials were grown either in the shade or in the open. In both the cases, higher numbers of inoculated branches developed blight symptoms as compared to the corresponding controls. Artificially infected branches also yielded A. strictum consistently. A significantly higher number of the inoculated culms of B. vulgaris developed infection as comapared to that of the controls. About one month after inoculation some of the inoculated culms were found to have developed necrosis on the culm sheaths. Removal of some of the culm sheaths revealed that discolouration also extended to the tender culm undernearth. A. strictrum was retrieved from the infected culm and culm sheath. Such culms developed a dead top within one month's time rendering the symptoms typical of bamboo blight (Rahman & Khisha, 1981).

In the present study A. stricturn has been found to be a primary pathogen of blight of B. balcooa and B. vulgaris (Table 2). This fungus has also been reported to cause leaf spot of Fig in Louisiana (Tim 1941). stalk rot (Gupta and Renfro 1972) disease of maize and leaf rot of Betelvine in India (Singh and Jeshi 1973), wilt of Chrysanthemum maximum in California (Chase, 1978, Chase and Munnecke 1980), stem necrosis of Sunflower IN Indiana (Richerson 1981), black bundle disease of corn (Barnett and Binder 1973). brown stem rot of Soybean (Presley and Allington 1947). Chase and Munnecke (1980) also noted that the host plant had to be stressed by excessive soil moisture or by the onset of flowering to obtain symptoms comparable with those on field symptoms. Unlike A. stricturn infections of Maize (Raju and Lal 1977) or C. maximum (Chase and Munnecke 1980). development of symptoms in bamboo was observed from the early stages of culm growth. It is suggested that in the case of bamboo blight, infections were soilborne and occurred before or during emergence of new culm through the soil.

Field Trials To Control Bamboo Blight

In a recent experiment six blighted clumps of B. vulgaris in Chittagong were treated with Copper oxychloride and five clumps with Dithane M 45 (a complex of zinc and maneb containing 20% managese and 2.5% zinc) as soil drench in late July 1984. Five almost similarly blighted clumps were kept untreated

Table 3. Effect of cultuml measures and fungicfdal treatments on the survival of new culms of bamboos.

Species (locality)	Treatments	Number of clumps	Number of new culms Developed	Number of new culms Survived	% survival	CV%
B. balcooa (Rajshahi)	Blighted bamboos cut and removed, debris burnt in clumps and new soil added.	15	568	263	43.30’’	28.90
	Blighted bamboos cut and removed, and new soil added.	5	120	35	29.17	39.49
	Controls	9	338	99	29.29	21.77
B. vulgaris (Chittagong)	Soil drenched with Cupravit	6	305	91	29.84	68.11
	Soil drenched with Dithane M 45	5	188	101	53.72	36.74
	Controls	5	172	34	19.77	56.65

and served as controls. The number of healthy and dead culms were observed at regular intervals from 3rd August, 1984 until January, 1985. The results of the above experiments on the survivality of new culms are presented in Table 3.

Cutting and removing blighted bamboos, burning the debris of clumps in situ and addition of new soil to clumps promoted the production of higher number of surviving healthy bamboos in comparision with that of the controls. Cutting and removing blighted bamboos and adding new soil to clumps (without burning) had no significant effect on the survival of new culms. Hence, the significant increase in the number of survival of new culms is most likely due to the direct and/or indirect effect of burning. The direct effect of burning may result in a reduction in the inocula potential of pathogenic fungus which existed in the debris or in the top few inches of soil. The indirect effect may be due to the addition of ash in the soil which might have acted as a manure. Drenching soils of the bamboo clumps which had bamboo blight with either Copper oxychloride or Dithane M 45 proved to be beneficial as compared to the control clumps. Dithane M 45 soil drench was better than Copper oxychloride treatment. The difference was not, however, significant because of high variability among the clumps.

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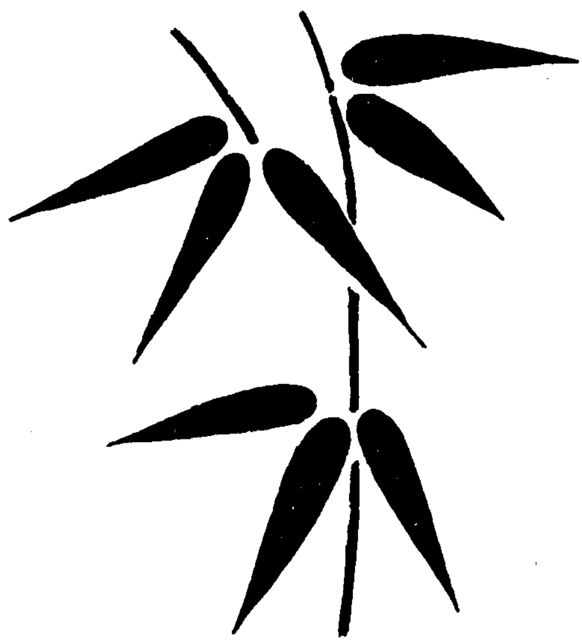

Fungal Diseases of Bamboo
A Preliminary and Provisional List

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Abstract

Information on the fungal diseases of bamboo is *collated* and the importance of *the* diseases is discussed. The need for further work is indicated and certain methods of study are suggested.

Introduction

This is the first attempt to collate information on fungal diseases of bamboo as recorded throughout the world. In practice, this will refer largely to countries in Asia, particularly India and Japan; only a limited number of records have been found for bamboo diseases in Africa and Central and South America. Within Asia there are several countries, for instances, the Philippines, Indonesia and Burma, for which little information is available. By comparison many records exist for bamboo in the U.S.A. (Anon, 1960) which reflects more on the activity of pathologists than on the impor: tance of either bamboo or bamboo diseases Several Japanese works have been consulted on bamboo diseases: Kusano (1908) lists bamboo leaf rusts whilst Kawamura (1929) and Hino (1961) are more general. Bamboo diseases in India are usefully summarised by Butler and Bisby (1960) and Bakshi (1976). These consider inter alia two very important and widespread bamboo host genera, Bambusa and Dendrocalamus. Japanese workers have been largely concerned with *Sasa* and its allies, and to a lesser extent Phyllostachys. Spaulding (1961) records many of the bamboo diseases. It is unfortunate, given the lack of data on symptoms and disease losses, that the original sources for the data which is presented are not given. This lack of information on bamboo diseases has, however, been a constant problem in any attempt to compile a comprehensive list of bamboo diseases. Even where I was able to consult original papers only a limited amount of detail was available.

Many of the original references to bamboo diseases are not available, often because of difficulties in obtaining journals. Several references were obtained from two annotated bibliographies (Elbourn, 1978; Ridout, 1983), which together cover the Review of Plant Pathology (RPP) from 1973-1982. Earlier issues of the RPP were also consulted.

Scope of Bamboo Disease List

Only fungal diseases are considered There are many records of deuteromycetea (Ellis, 1971, 1976; Sutton, 1980) on bamboo but most of these have no association with a disease.

I have treated many of the records of higher fungi (mainly polypores) producing rots on living bamboo with some circumspection. Bagchee and Singh (1954), for instance, give many instances of decay fungi which I have considered to be of dubious significance, and which have been omitted from below in the absence of data from another source. Those rot and decay fungal records that are listed should be treated with some caution (eg. Fomes spp.) since it is not clear which part of the bamboo is attacked – rhizome or culm.

One bacterial disease of bamboo in Taiwan (Lo et *al.*, 1966) has been included. However, viruses (Anon, 1977; Kitajima *et* al., 1977; Lin et al., 1977), mycoplasmas (Nayar and Ananthapadmanabha, 1977) and mistletoes have been excluded. Similarly decays and rots of cut bamboos are not considered. There is no suggestion that bamboo viruses cause any damage to their hosts. A series of papers by Kwan Soo Kim (1979) and Kwan Soo Kim and Ji-Yul Lee (1980) investigated the soil-borne fungi of ***Phyllostachys*** reticulata forests in Korea. None of these fungi were associated with any disease of bamboo.

Importance of Bamboo Diseases

The relative importance of the different diseases is difficult to assess because of the general lack of information accompanying each disease record. Despite this the overall impression is that many of the bamboo diseases are of only limited importance. It became apparent when compiling the list that the higher fungi (e.g. polypores and ascomycetes) had been more frequently recorded (perhaps because of their distinct fruiting bodies) than the deuteromycetes. The hyphomycetes in particular are much under-represented and this, I feel, represents a lack of investigation into bamboo micro-fungi rather than an absence of pathogens in this group. There is no suggestion that any of the many leaf spot fungi, leaf rusts and decay pathogens cause more than minor damage. Severe attacks by rust fungi on bamboo have been noted, but only infrequently and with only localized damage. By comparison the diseases of growing or young culms are much more serious, with extensive damage reported for bamboo blight (on ***Bambusa*** spp.) in Bangladesh, (Boa, this volume) and blight on Phyllostachys in China.

Bamboo Blight in Bangladesh

This important new disease of growing culms of Bambusa spp. is not included in the list of diseases below because we are still uncertain about its etiology. Elsewhere in these proceedings (Boa: Rahman) the sheath rot pathogen of rice Sarocladium ***oryzae,*** and Acremonium strictum are both linked with bamboo blight, particularly the former, but a connexion between a fungal and the disease has still not been adequately demonstrated.

Further Work Required

1. Many of the records of diseases are quite old. It is important that these be updated, together with a more complete picture of the disease; for example. a full description of symptoms and losses due to the disease.

2. The present records for bamboo disease do not adequately consider the very important although widely dispersed resource of rural village bamboos.

3. The ***growing*** culm has received little attention with regard to disease. Young, green, wet tissue is more likely to be damaged by pathogenic organisms, and to a greater extent, than mature culms.

There are several cryptic references to the death of new shoots at a very early stage. Pathological studies of these dying culms are required to establish whether this apparently widespread phenomenon is due to a living ***or*** non-living (e.g. soil conditions) agent.

4. The culm sheaths play a very important part in the development of new culms. If green culm sheaths and/or the not fully expanded internode below are damaged, for example by insects, this has an apparently dramatic effect on the proximal part of the growing culm. The effect certainly extends much beyond the area damaged and suggests that culm sheaths and the internodes that they protect are particularly susceptible to damage. Again this is an area to be investigated more fully.One of the difficulties here is that culm sheaths naturally have a very short existence (approximately four weeks for ***Bambusa*** vulgaris in Bangladesh) and it can be difficult to discern accurately the development of abnormal necroses.

Format of Bamboo Disease Listing

Diseases are listed alphabetically by the fungal (bacterium in one instance) associated with the symptoms. I have briefly described the type of fungus (e.g. Aphyllophorales (polypores), ascomycete etc.) the name of the disease, countries and hosts in which it occurs, are also given together with a list of appropriate references. I have not listed texts such as Bakshi (1976) and Browne (1968) unless these are the ***only*** references.

I have not listed authorities for either host or pathogen; this detail was not always available in the papers consulted.

List of Fungal Bamboo Diseases

(1) Aciculosporium *take* WITCHES BROOM (Japan; Taiwan)
Ascomycete
on Phyllostachys aurea; *P.* bambusoides; *P.* lithophila; P. malcinoi; *P.* nigra; *P..* nigra var henonis; *P.* pubescens.
C. Chen (1970, 1971); Kao and Leu (1976); Lin *et* al. (1981); Nozu and Yamamoto (1972) : Shinohara (1965) ; Spaulding (1961).

(2) Amauroderma rugosus (sic) CULM DECAY (India)
Aphyllophorales
on Bambusa
Banerjee and Ghosh (1942)

(3) Armillaria *mellea* PATHOGEN? (Kenya)
Agarioales
associated with Arundinaria alpina
Gibson (1960)

(4) Asterinella hiugensis BLACK MILDEW ON CULMS (Japan)
Ascomycete
on Phyllostachys bambusoides
Spaulding (1961)

(5) Astrosphaeriellafuscomaculans SPECKLED CULMS (Japan)
Ascomycete
on Phyllostachys nigra
This infection enhances the value of the culms!

(6) Balladyna butleri BLACK LEAF SPOT (India)
Ascomycete
on Bambusa sp.
Butler and Bisby (1960)

(7) Calocline chusqueae LEAF LESIONS (Ecuador)
Coelomycete
on Chusquea
Sutton (1980)

(8) Ceratosphaeria phyllostachydis SHOOT BLIGHT (China)
Ascomycete
on Phyllostachydis edulis

(9) Cladosporium graminum LEAF MOULD (U.S.A.)
Hyphomycete
on Phyllostachys aurea
Anon (1960)

(10) Clavaria spp. SHOOT ROT (Thailand)
Basidiomycete
on Bambusa spp.
Giatgong (1980)

(11) Coccodiella arundinariae LEAF SPOT (China, Japan)
Ascomycete
on Phyllostachys sp.
Spaulding (1961)

(12) Colletotrichum graminicola ANTHRACNOSE (U.S.A.)
Coelomycete
on Arundinaria gigantea
Anon (1960)

(13) Colletotrichum hsienjenchang CULM BLIGHT/ROT (Japan)
on Phyllostachys bambusoides; *P.* nigra var. henonsis
Spaulding (1961)

(14) Coniosporium bambusae SHOOT WILT (U.S.S.R.)
Hyphomycete
on Phyllostachys spp.
Beradze (1972), (1973a), (1973b), (1974), (1975a), (1975b)

(15) Corticium lcoleroga THREAD BLIGHT (LEAF AND CULM DAMAGE) (India)
Aphyllophorales
on Dendrocalamus sp.
Browne (1968)

(16) Dasturella bambusina LEAF RUST (India)
Uredinales
on Bambusa sp.
According to Bakshi (1978) the original specimen when re-examined showed the host to be Dendrocalamus strictus. He also noted that the telia of *D. bambusina* and *D. dioina* were the same.
Mundkur and Kheswalla (1943)

(17) Dasturella diuina LEAF RUST (India; Vietnam; Pakistan; Japan)
Uredinales

on *Dendrocalamus sp.; D. strictus; Oxytenanthera abeysannae* (fide Bakshi *(1968); Ox. abyssinica* (fide Thiruma-Iachar and Gopalankrishnan (1947)). Alternative hosts *Randia* and Xeromphis (Angiosperms).

Bakshi and Sujan Singh (1967); Spaulding ,(1961); Sujan Singh and Bakshi (1964)

18) *Dicellomyces gloeosporus* LEAF SPOT (U.S.A.)

Basidiomycete

on *Arundinaria tecta*

Anon (1960)

(19) *Diplodia* bambusae TIP BLIGHT (U.S.A.)

Coelomycete

on "other bamboo spp."

Anon (1960)

(20) *Encoelia helvola* CULM ROT (Indonesia)

Ascomycete

on Bambusa spp.; Bambusa *arundinacea; Gigantochloa apus*

Overeem (1926) ; Rifai (1983)

(2 1) *Epichloe bambusae* WITCHES BROOM (Indonesia)

Ascomycete

on Bambusa vulgaris; Dendrocalamus asper; Gigantochloa apus; G. atter; G. verticilliata

Rifai (1983)

(22) *Erwinia sinoclami* BACTERIAL WILT (Taiwan)

Bacterium

on "Taiwan giant bamboo"

Loetal. (1966)

(23) Fomes *lignosus* WHITE ROOT ROT (Malaysia)

Aphyllophorales

on *Dendrocalamus giganteus*

Browne (1968) ; Hilton (1961)

(24) *Fusarium moniliforme* BASAL CULM ROT (China)

Hyphomycete

on *Phyllostachys* pubescens

J. Chen (1982)

(25) *Fusarium solani* CULM BROWN ROT (China)

Hyp homycete

Lan (1980)

(26) Ganoderma *lucidum* ROOT ROT (India, Pakistan, Philippines

Aphyllophorales

on *Bambusa sp. B. arundinacea*

Bakshi (1957); Banerjee and Ghosh (1942) ; Butler (1909) ; Spaulding (1961)

(27) *Helminthosporium* sp. LEAF SPOT (U.S.A.)

Hyphomycete

on *"other bamboo spp."*

Anon (1960)

(28) Hughesinia *chusqueae* LEAF SPOT (C hile)

Hyphomycete

on *Chusquea*

Ellis (1976)

(29) *Hypoxy lon rubiginosum* CANKER/ WHITE POCKET ROT (India)

Ascomycete

on *Bambusa*

Bagchee and Singh (1954)

(30) *Hypoxylon fuscopurpureum* CANKER (India)

on *Bambusa*

Bagchee and Singh (1954)

(31) *Irpex flavus* SPONGY SAP ROT (India? Ghana? Pakistan)

Aphyllophorales

on *Bambusa* sp.

Browne (1968)

(32) *Leptothyrium cylindrium* LEAF SPOT (U.S.A.)

Coelomycete

on *Arundinaria tecta*

Anon (1960)

(33) *Loculistroma bambusae* WITCHES BROOM (China)

Ascomycete

on *Phyllostachys*

Anon (1911)

(34) *Meliola bambusicola* BLACK MILDEW (India)

Ascomycete

on *Bambusa* sp.

Browne (1968); Butler and Bisby (1960)

(35) Meliola *tenuis* BLACK MILDEW (U.S.A.)

on *Arundinaria gigantea; A. tecta*

Anon (1960)

(36) *Merulius similis* CULM DECAY (India)

Aphyllophorales

on Bambusa bambos

Banerjee and Bakshi (1945); Banerjee and Ghosh (1942) ; Banerjee and Mukhopadhyay (1962)

(37) *Mycosphaerella sp.* LEAF SPOT (U.S.A.)

Ascomycete

on *Phyllostachys bambusoides; P. nigra*

Anon (1960)

(38) *Mycosphaerella* arundinariae LEAF SPOT (U.S.A.)

on *Arundinaria tecta*

Anon (1960)

(39) *Myrangium* bambusae 'SEVERE PARASITE" (C hina)

Ascomycete

on *Phyllostachys pubescens*

Tai (1931)

(40) *Papularia arundia (= Arthrinium* state of *Apiospora* Hyphomycete *montagnei* fide Ellis (1965)) on *Bambusa* sp. CULM SOOTY STRIPE? (India)

Ellis (1971) makes no mention of this common bamboo fungus as a pathogen. I have frequently observed *Arthrinium* freely sporulating on dead culm and twigs. Bagchee and Singh (1954); Thirumalachar and Pavgi (1950) Phyllachora spp _LEAF SPOTS

Ascomycete

Five species recorded widely

(41) *Phyllachora arundinariae* (U.S.A.)

on *Arundinaria tecta*

Anon (1960)

(42) *Phyllachora bambusae*

(43) *Phyllachora malabarensis (India)*

(44) *Phyllachora shiraiana*

on *Bambusa* spp. Noted as being of little importance.

Butler and Bisby (1960)

(45) *Phyllachora chusqueae* (U.S.A.)

on "other bamboo spp."

Anon (1960)

(46) *Polyporus*

Aphyllophorales

on *Dendrocalamus strictus*

Cause of death noted as *Polyporus,* in conjunction with *Poria* and Rhizoctonia (see Sheikh et al. (1978)

(47) *Polyporus durus* DECAY (India)

on *Bambusa*

Banerjee and Ghosh (1942)

(48) *Polyporus* friabilis DECAY (India)

on *Bambusa*

Banerjee and Ghosh (1942)

(49) *Poria* rhizomorpha ROOT ROT (India, Bangladesh (given as Pakistan))

on *Melocanna baccifera*

Spaulding (196 1)

(50) *Puccinia* spp. RUSTS (U.S.S.R.)

Uredinales

on bamboo – no other information available.

Beradze (1972)

(5 1) *Puccinia arundinariae* LEAF RUST (U.S.A.)

on *Arundinaria gigantea*

Anon (1960)

(52) *Puccinia gracilenta* LEAF RUST (India)

on *Bambusa* sp.

Bakshi and Sujan Singh (1967); Butler and Bisby (1960)

(53) *Puccinia ignaua* LEAF RUST (U.S.A.)

(see also Uredo ignava)

on *Bambusa vulgaris*

Anon (1960)

(54) *Puccinia kusanoi* LEAF RUST (Japan, U.K.)

on *Arundinaria, Sasa, Semiarundinaria fastuosa,* Alternative host *Deutzia* (Angiosperm)

Reid (1978); Reid (1984) ; Spaulding (1961)

(55) *Puccinia Iongicornis* LEAF RUST (China, Indochina, Japan, U.K.)

Uredinales

on *Arundinaria, Bambusa arundinacea, Phyllostachys, Sasa.*

Reid (1978) ; Spaulding (1961)

(56) *Puccinia phyllostachydis* LEAF RUST (India, China, Japan, U.S.A.)

(Also as *P. melanocephala)*

on *Arundinaria suberecta; Phyllostachys aurea; P. bambusoides; P. nigra* var henonsis

Browne (1968) says that *P. phyllostachydis* is the correct name for *P. melanocephala* as given by, for example, Butler and Bisby (1960).

Other references: Anon (1960); Bakshi and Sujan Singh (1967); Spaudling *(1961)*

(57) *Puccinia xanthosperma* LEAF RUST (India)

Uredinales

on *Bambusa sp.*

. Bakshi and Sujan Singh (1967); Butler and Bisby (1960)

(58) *Pyricularia* sp. LEAF INFECTIONS (Japan)

Hyphomycete

on *Phyllostachys; P. oryzae;* Semiarundinaria spp.; S. viridis; Shibateae; *Tetragonocala mus.*

Itoi et *al. (1978), (1979)*

(59) *Pyricularia grisea* LEAF SPOTS (Pantropical)

on Bambusa

Ellis (1971)

(60) Rhizoctonia DEATH OF CULMS,' CLUMP (Pakistan)

Agonomycete

See note for Polyporus

(61) *Scolecotrichum graminis (= Scilecotrichum gra minis)*

Hyphomycete BROWN STRIPE OF CULM (U.S.A.)

on Arundinaria tecta

Anon (1960)

(62) *Sclerotium rolfsii* CULM ROT (U.S.A.)

Agonomycete

on *Bambusa vulgaris*

Anon (1960)

(63) *Selenophoma donacis* CULM SPOT (U:S.A.)

Coefomycetes

on "other bamboo spp."

Anon (1960)

(64) *Shiraia bambusicola* CULM SHEATH PATHOGEN? (China)

Ascomycete

on Phyllostachys sp

Tai (1932)

(65) *Stereostratum corticioides LEAF AND STEM RUST (China, Japan, Pakistan)*

Uredinales

on *Arundinaria. P. bambusoides, P. nigra var henonis*

Spaulding (196 1)

(66) Stereum percome DECAY (India)

Aphyllophorales

on *Bambusa*

Banerjee and Ghosh (1942)

(67) *Tomentella bambusina* CULM WILT (Brazil)

Aphyllophorales

(Tomentella = Trechispora)

on *Bambusa vulgaris*

(68) *Trametes corrugata* DECAY (India)

Aphyllophorales

on *Bambusa*

Banerjee and Ghosh (1942)

(69) *Tunicopsora bagchii* LEAF RUST AND TWIG DEATH/WITCHES BROOM (India)

Uredinales

on *Dendrocalamus strictus*

Bakshi et al. (1972); Sujan Singh and Pandey (1971)

(70) *Uredo dendrocalami* RUST (SriLanka. China)

Uredinales

on *Dendrocalamus.* D. latiflorus

Spalding (1961)

(71) *Uredo ignava* LEAF RUST (China. Cuba. Puerto Rico, Venezuela)

(See P. ignava)

on Bambusa arundrnacea. B vulgaris. Dendrocalamus sp.

Spaulding (196 1)

(72) *Ustilago shiraiana* SHOOT DEATH

WITCHES BROOM (China, Japan, Taiwan, U.S.A.)

Ustilaginales

on *Bambusa* spp., *Phyllostachys bambusoides, P. nigra*

Anon (1960); Hori (1905); Patterson and Charles (1916); Speulding (1961)

(73) Volutella tecticola LEAF SPOT (U.S.A.)

Hyphomycete

on *Arundinaria tecta*

Anon (1960)

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The Occurrence and Bamboo Blight in Bangladesh with Reference to Sarocladium oryzae

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Abstract

The symptoms of a blight of Bambusa spp. are described fully for the first time. The disease has only been recorded from Bangladesh and has been present since the early 1970s. Bamboo blight attacks village bamboos; in particular B. balcooa and B. vulgaris, the two most important species; the forest bamboos, dominated by Melocanna baccifera, are not affected. Details are given of the losses in bamboo clumps resulting from blight attack. Isolations from blight symptoms have consistently yielded Sarocladium oryzae, the sheath rot pathogen of rice. Limited artificial inoculations with this fungus on bamboo have resulted in symptoms similar to blight, but much more work is required before the cause of bamboo blight is fully understood. There is much insect damage in blighted culms and observations suggest that these insect(s) are responsible for introducing S. oryzae into Ihe culm via feeding holes.

Introduction

There are few serious diseases of bamboo. It was therefore with some alarm that a brief note by Rahman and Zethner (197 1) recorded a damaging new disease, which they called bamboo blight, from village bamboo groves of the Rajshahi district of Bangladesh. Subsequently little information was available on the disease, although there is no doubt that it continued to be a major source of worry to local farmers. Since 1982 a comprehensive research programme has been carried out by myself and Dr M A Rahman of the Forest Research Institute, Chittagong. A colour brochure which describes the disease in outline has been produced (Boa and Rahman, 1984); the present paper provides a more complete description of blight symptoms and reports the results of isolations of fungi from diseased and healthy tissues together with a discussion on the cause of the disease.

The chronology of research on bamboo blight is as follows: 1971 – Disease first recorded in a brief note by Rahman and Zethner (1971); 1975 Gibson (1975) during a brief visit to Bangladesh reported the disease from additional areas; 1978 – Rahman (1978) described the results of isolations from blighted bamboo; and 1982 – Bamboo blight project commences with the help of the British Technical Cooperation Programme.

Bamboo Species in Bangladesh and those which become Blighted

Bamboos in Bangladesh can be divided into two groups: the forest bamboos and the village bamboos. The latter are dominated by *Bambusa balcooa* (Fig. la), and are generally thick-walled and form compact clumps with large culms 15-20 m. The former are dominated by *Melocanna baccifera* (Fig. lb) and are thin-walled with small 'culms up to about 10 m and both the species have pachymorph rhizome systems. The village bamboos are found throughout the flat. deltaic regions of Bangladesh and the forest bamboos in the upland regions (Chittagong Hill Tracts and

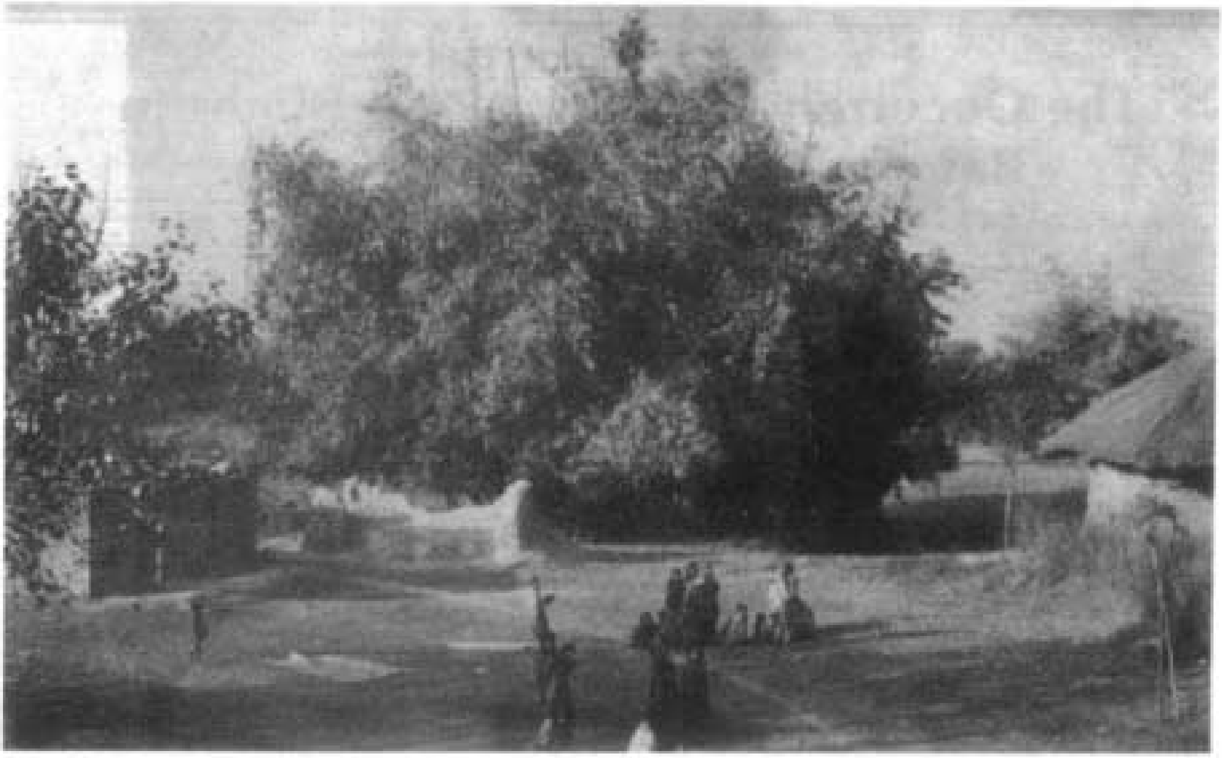


Fig. 1a. Village bamboo — *Bambusa balcooa*.

Fig. Ib. Forest bmboo – *Melocanna baccifera.*

Sylhet region) although it is not uncommon to find M. baccifera growing in villages.

Table 1 shows the iwo most affected species are B. balcooa and B. vulgaris. "Jawa" bamboo is known only by its local name: on the basis of general appearance and fringed auricles on its culm sheaths. It would appear to be a Bambusa sp. B. tulda sensu lato (see Boa and Rahman, 1984, for a description) refers to a group of bamboos that are difficult to separate on the basis of vegetative characteristics and also show the same type of blight development. The grouping of these bamboo types into B. tulda s.l. is made here for practical purposes only and is not meant to have any taxonomic validity, Alam (1982). who provides a recent description of bamboo species in Bangladesh, separates B. tulda s,I. into three separate species. The species described by Alam which occur in villages, and are not mentioned in Table 1, are of little importance and none have been seen blighted, This includes Dendrocalamus giganteus Nunro, for example.

Bamboo blight has only been recorded from Bangladesh. Enquiries by the Forest Research Institute of India to State Forestry Departments yielded no records of blight

Table 1. Important bamboo species occurring in Bangladesh villages and the presence of blight.

Species	Notes on distribution	Over811 severity of field attaCk	Degree of disease development in *single clumps*
Bambusa balcooa Roxburgh	Widespread and abundant except for SE	+ +"	1 – 4[b]
B. glaucescens (Willd .) Sieb. ex Munro	Locally common in NE	NONE	NONE
B. polymorpha Munro	Sporadic in NE and SE, perhaps elsewhere	NONE	NONE
B. tulda sensu lato (see text)	Widespread though + often locally sparse except in N	+	1 -2
B. vulgaris Schrader ex Wendland	Dominant in SE but sporadic elsewhere	+ + +	3-4
"JAWA" (local name – ***Bambusa*** sp .?)	Common in W generally – absent elsewhere?	+ +	2-3
Cephalostachyum ***pergracile*** Munro	Apparently present in N only	NONE	NONE
Melocanna baccifera (Roxburgh) Munro	Generally E of Jamuna river, widespread though patchy and sparse	NONE	NONE

'+ low,+ + + high
bl (Minor) 25% new culms blighted; 2 (Mild) 25-50%;
3 (Moderate) SO-75%; 4 (Severe) 75%

(Sujan Singh, pers. comm.). Of the species listed in Table 'I which develop blight, B. *vulgaris* is the only one of widespread importance. Gamble (1896) states that B. *balcooa* occurs only in Assam and what is now Bangladesh . B. vulgaris, however, occurs extensively throughout Asia from India to Malaysia (Holttum, 1958), Indonesia and elsewhere. B. tulda s.1. is grown mainly in the Indian subcontinent (Gamble, 1896).

Symptoms of Bamboo Blight

Bamboo blight is easily recognized in the field. in its later stages, by the presence of truncated culms which show varying degrees of die back (Fig. 2a). Below this dead portion partial necrosis ("streaking" – Fig. 3) is usually present. Streaking may extend directly from the dead part of the culm or may occur lower down as discrete areas (Fig. 6a). Blight only attacks growing cuims and is thus best observed from about July through November. If a culm is still healthy after complete expansion has taken place, it will remain so. Culms are attacked at various stages of development, in some cases when they have already grown to 8 m or more, but observations of the first stages of disease development have been made on culms which became blighted when 1-4 m tall. Once a culm shows even slight development of blight symptoms – at which stage no die back or streaking is present – then it ceases growth.

Symptoms develop initially on internodes which are still growing and which are approximately 40-60 cm below (Fig. 4a – far left culm) the culm apex. At this stage of densely compacted internodes above -show no signs of symptoms either on the surface or internally although subsequently these will develop and the apex will die.- These initial symptoms on growing internodes cannot be deteced by external examination of the culm since the supporting culm sheaths are

Fig. 2a. Die back of 5 month-old culms. Note the different stages of culm growth at which blight attacks.

Fig 2b Die back ends at node

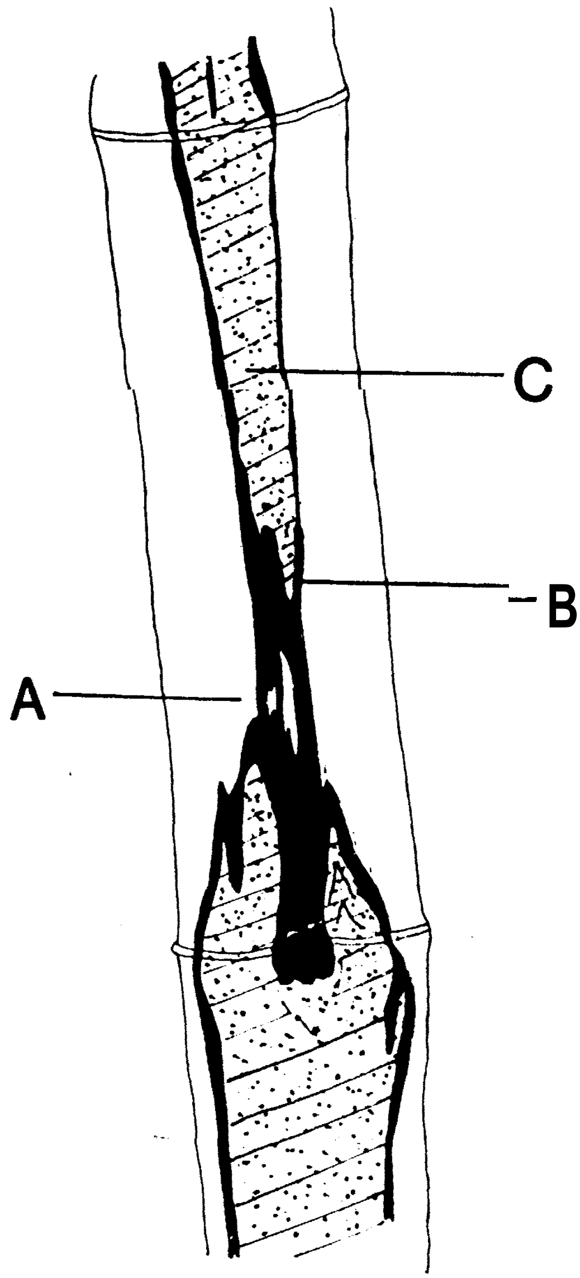


Fig. 3. Streaking of blighted culm. Three zones can be seen: A Orange/yellow discoloration, little or no stain below; B. Black/brown, stain below and usually insect channels; C. Culm wall dead, light brown, "dried out", often with fissures and long irregular cavities.

still in place, but their presence is indicated by a premature death of these culm sheaths. Removal of the culm sheaths reveals dark stained areas, almost always associated with insect holes and channels (Fig. 4b). The black staining extends above and below the insect hole, with reduced lateral spread, and often to the depth of the inner culm wall. Black stained areas eventually become necrotic. If necrosis develops sufficiently then die back will occur (Fig. 2b) otherwise the production of defence barriers (Fig. 5a) will restrict spread and result in streaks (Fig. 3).

Insects are obviously of great importance inspreading blight symptoms within the culm and also in introducing the disease. In several culms insects had eaten through a healthy culm sheath and burrowed into the underlying expanding culm tissue, where black staining was seen around the edge of the insect channels. In other cases the spread of symptoms was clearly linked with the burrowing of insects, for example as seen in older blighted culms (4-8 months) (Fig. 5). It is not clear whether the same insects are responsible for burrowing both into tender culm tissue and older harder tissue, and causing the blight. So far no attempts have been made to identify insect larvae found in culm walls. The development of blight in affected species is different, as shown in Fig. 6; for example culms of B. vulgaris are attacked at a much earlier stage of growth whilst culms of B tulda s.l. tend not to show any streaking.

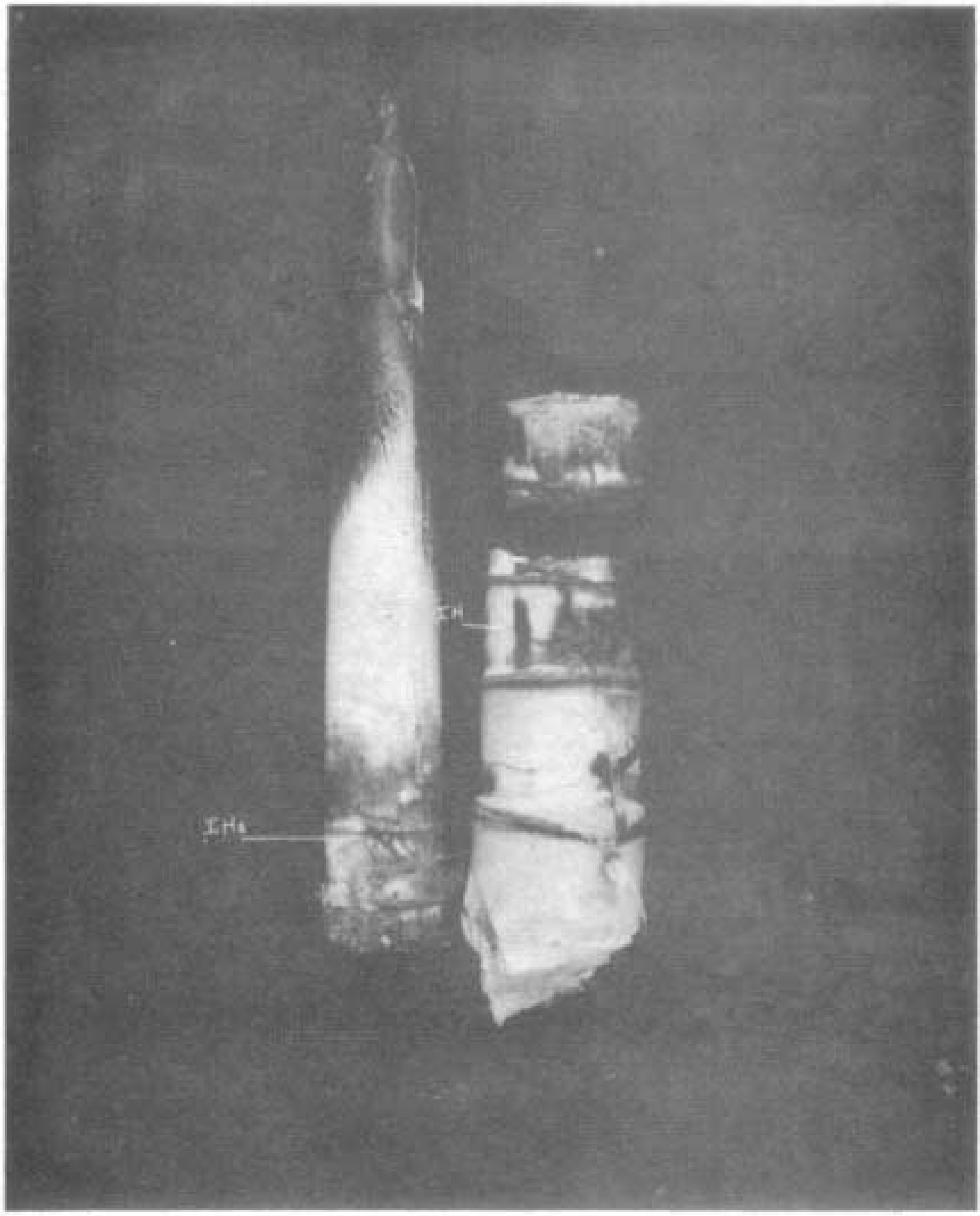
A feature of blighted bamboo in Bangladesh is the failure of new culms to grow beyond a height of about 40 cm (Fig. 7b). At this stage internodes are densley compacted and only a premature death of the culm sheaths indicates that the culm is dying. When these dying young culms are split open (Fig. 7c) the origin of the disease can be seen at the base. The apex is still symptomless at this stage and the basal rhizome region healthy.

There are also reports of dying young culms from other countries where blight has not been observed. I have witnessed this phenomenon on Gigantochloa in the Botanical Gardens, Bogor, Indonesia; Ueda (1960) carried out an extensive investigation into dying young culms on Pbyllostachys spp. in Japan and Iisiung (pers. comm.) has fre quently noticed this occurrence on Phyllostachys in China. It appears unlikely that dying young culms are part of the bamboo blight disease syndrome in Bangladesh although this topic needs more careful and detailed study to identify the cause of death.

Distribution of Bamboo Blight within Bangladesh

Bamboo blight has been seen throughout

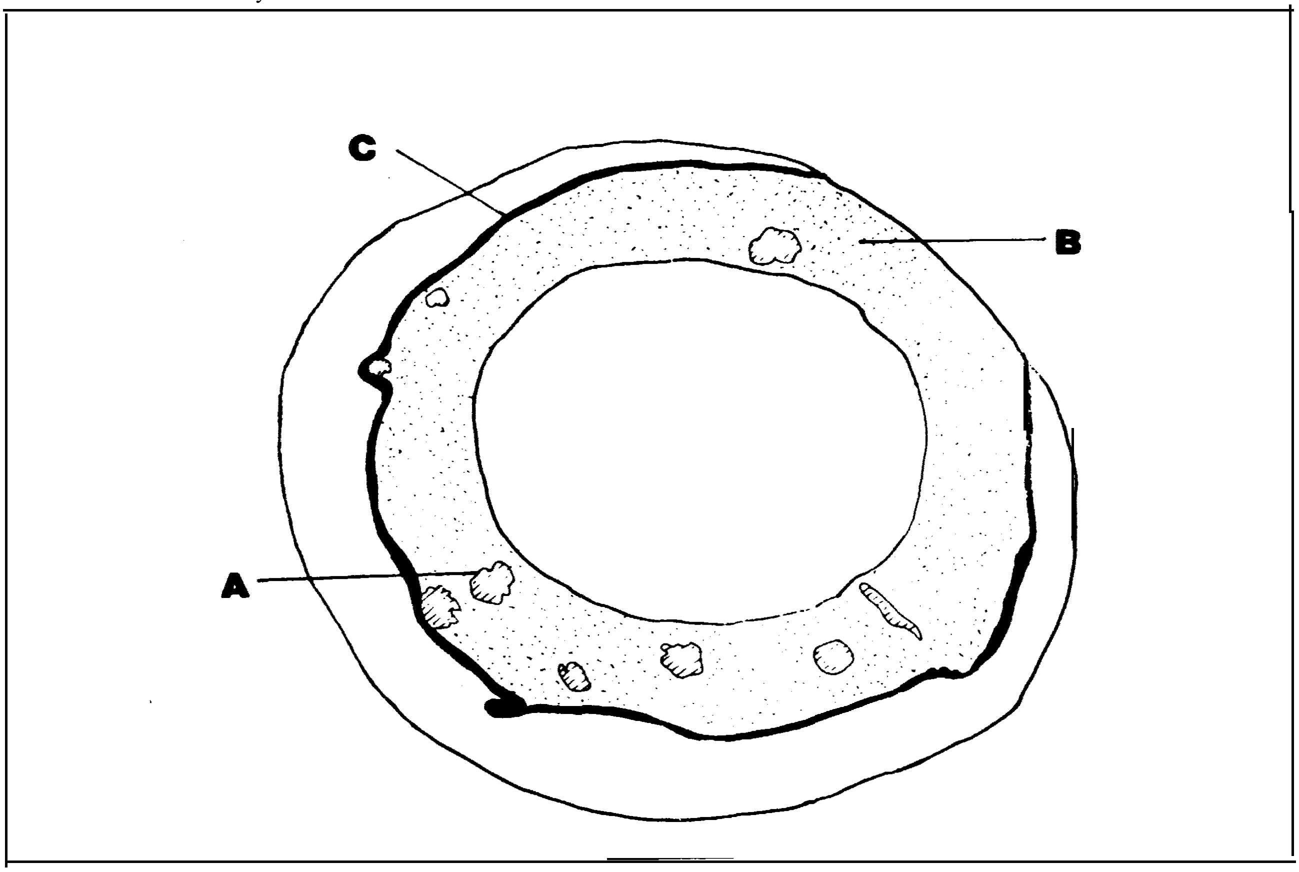
Fig. 4. *Bambusa vulgaris*. Young symptoms of blight. a) 3-6 week-old culms. Most culm sheaths have been removed to expose symptoms (note lighter colour of partially expanded internodes). Origin of first blight symptoms is shown by arrow; above is healthy. Insect holes (IH). b) 2-3 week-old culm. Extensive IHs and black staining. Basal culm sheaths removed.



4b

Bangladesh except the north-west (Fig. 8). The other main areas in which bamboo blight is absent are forest bamboos e.g. the east of Chittagong or village bamboos in areas near Barisal where blight occurs in relatively low numbers, The worst affected areas observed have been: 1) Dhaka and surrounding districts, particularly towards Comilla; 2) Pabna region (east of Rajshahi) and 3) Chittagong and surrounding areas. Outside of these three areas the presence of blighted clumps is patchy (Fig. 8). The absence of blight in the north-west can, to some extent, be accounted for by the dominance of *B. tulda s.l.* which shows a low incidence of blight in the other regions as well (Table 1). The absence of blight in the extreme south east might be due to improved conditions of growth for *B. vulgaris* compared to the Chittagong area, where non-blighted clumps of this species grow very poorly.

Fig. 5. Insect channels associated with internal staining: A) Oblique cross-section of 7 month-old culm. No external symptoms. (a) insect channels, (b) internal stain, (c) defence barrier restricts spread,* B) Longitudinal section through internode immediately below the extent of die back.



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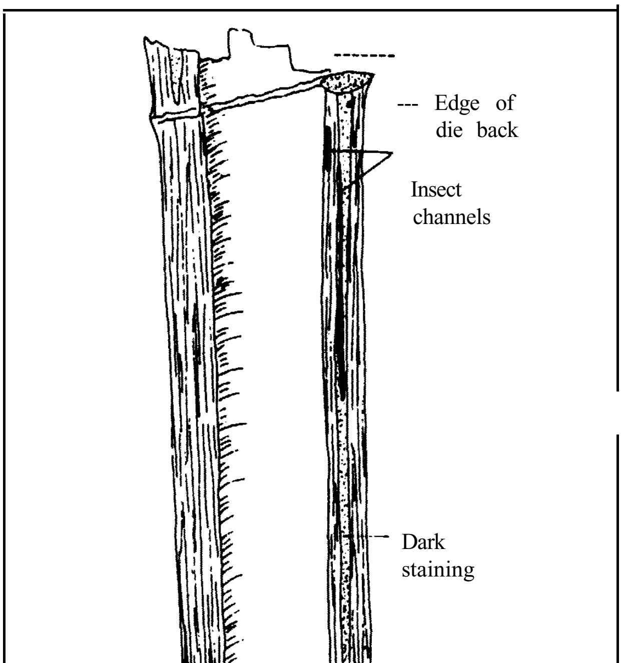
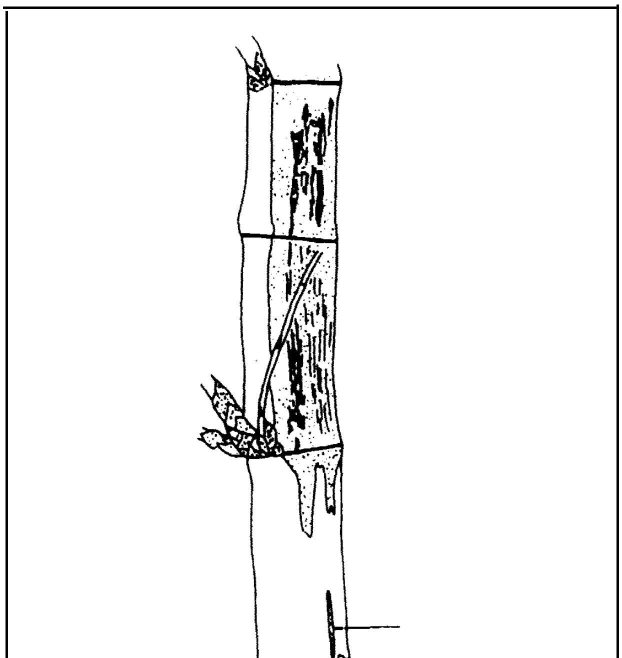
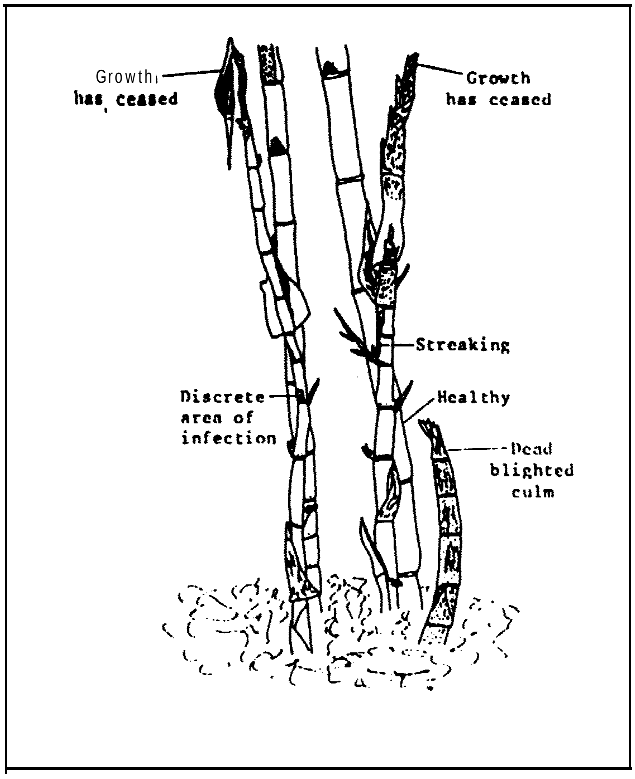




6a

6b



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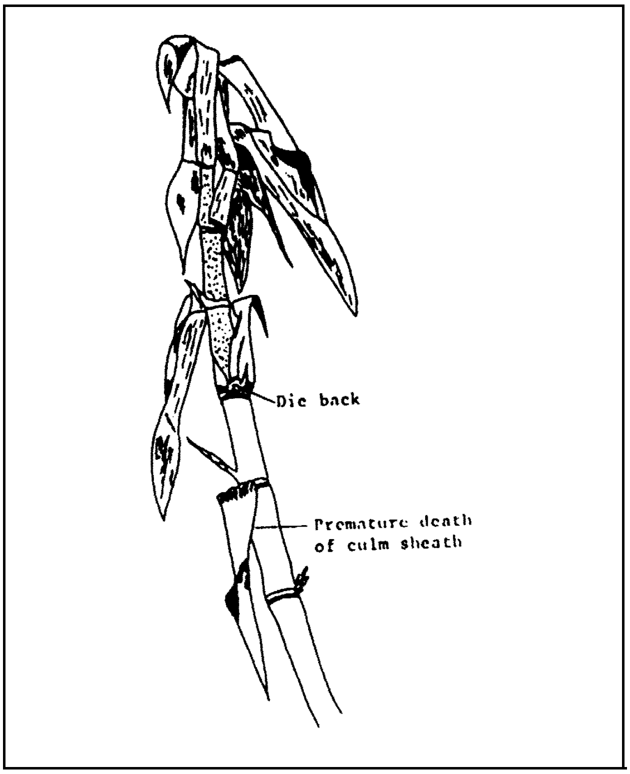


Fig. 6. Blight development in about 7 month-old culms: a) Bambusa balcooa, streaking on 8 m culm, die back (not shown) of above internodes. Note discrete areas of streaking (arrows); b) B. *vulgaris,* culms attacked at early stage of growth; c) 8. tulda s.1.

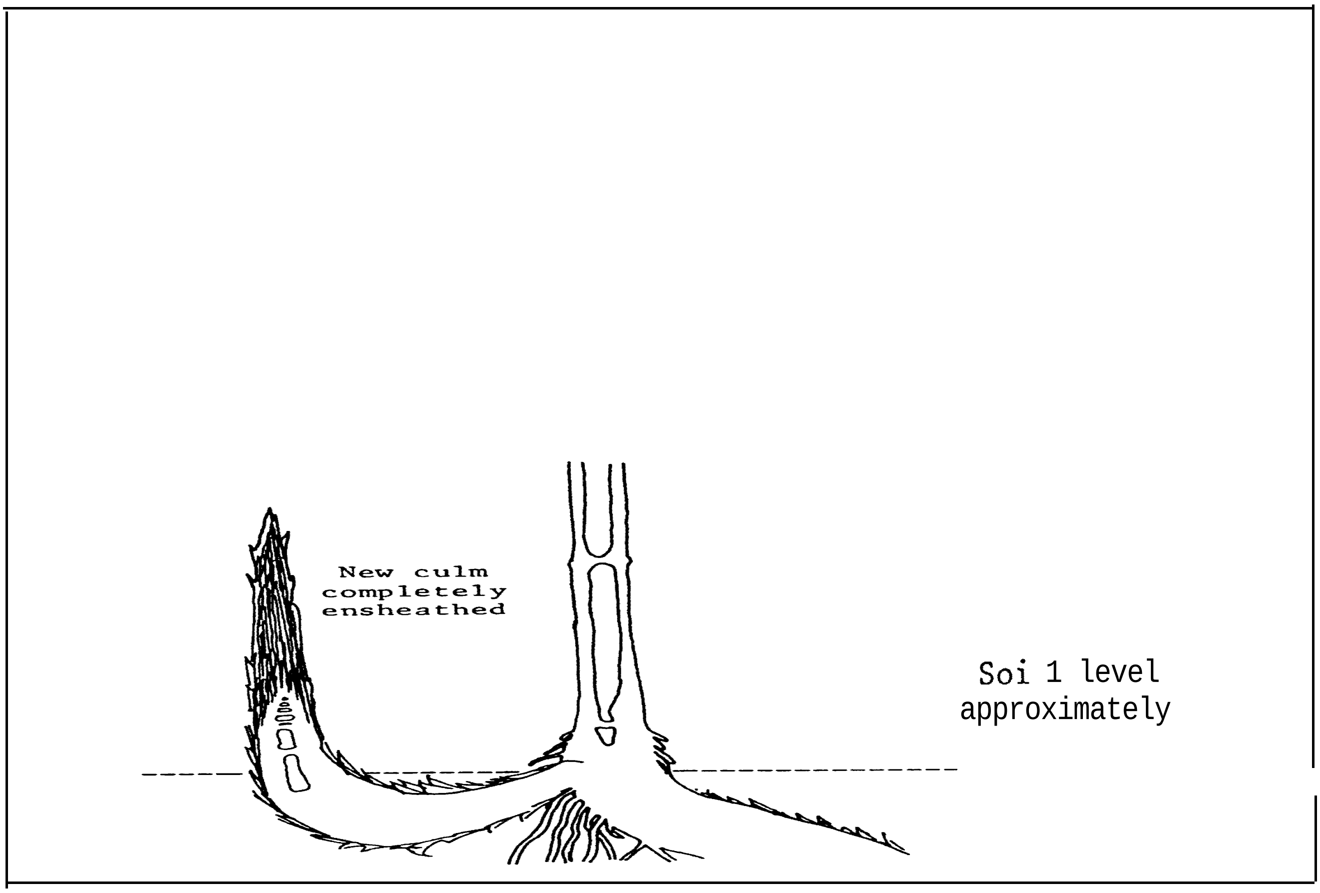


Fig. 7. New culms at early stage of development: a) New culm and mother culm from which it arises. The new culm is completely ensheathed at this stage; b) Dead new shoot of *Bambusa tulda* s.l. as seen in January; c) Dying new culm. f?. *balcooa,* wet stain in basal portion only, immature culm sheaths healthy.

7b

Spread of Bamboo blight between Clumps

Prior to 1982 there was little information available on either the extent of the disease or its severity in different regions. Initially blight was reported only from Rajshahi (Rahman and Zethner, 1971). Four years later Gibson (1975) recorded blight from Sylhet, in the north east (Fig. 8), as well as Khulna and Jessore. From 1982 to 1985 I have regularly visited different regions, in particular several small selected areas where healthy and blighted clumps have been kept under close observation, and there has been no evidence to indicate that blight is a fast spreading disease. In three cases only (all B vulgaris have healthy clumps adjacent to blighted clumps, become diseased It is therefore unlikely that bamboo blight first occurred only in the Rajshahi district: blight more probably arose in several different regions around the same time. It is difficult to envisage blight spreading from Rajshahi hundred miles to

7c

Sylhet in the space of four years. In 1985 blight was readily seen between Rajshahi and Nawabganj but there was every indication that the incidence had decreased, A high incidence of blight. was seen in Dhaka and other regions since 1982. This suggests that there has been wide spread of the disease but it also demonstrates that the status of blight is not static and may even be on the decrease.

Lasses in Bamboo clumps due to Blight

Selected clumps of healthy and blighted bamboo from Chittagong, Sylhet and Rajshahi were marked for all the new culms that appeared in 1983. and these new culms monitored monthly throughout the growing season. Final assessments were then made and culms divided into three classes: 1) healthy; 2) blighted; 3) dead yong culms (Fig. 7b). Observations were made mainly of blighted clumps of B. vulgaris and B, balcooa, Results show (Fig, 9) that more new culms in the B. vulgaris sample became blighted, although other observations have shown similar levels of disease in some clumps of blighted N. *balcooa,* Culms of B, vulgaris become blighted at an earlier stage in their growth, and subsequently blight symptoms extend further down the culm (Fig. 10). InB, *balcooa* there is a tendency for new culms to become blighted after expanding to 8 m or more (Fig. 2a); in B. vulgaris culms are attacked at a much earlier stage (Fig. 6c), the consequence of which is that more culms are completely killed (Fig. 10). This is an unusual event in blighted clumps of B. balcooa. In both species the progress of die back is limited (Fig. 2b) and only occurs during or soon after the growing season has finished. There is

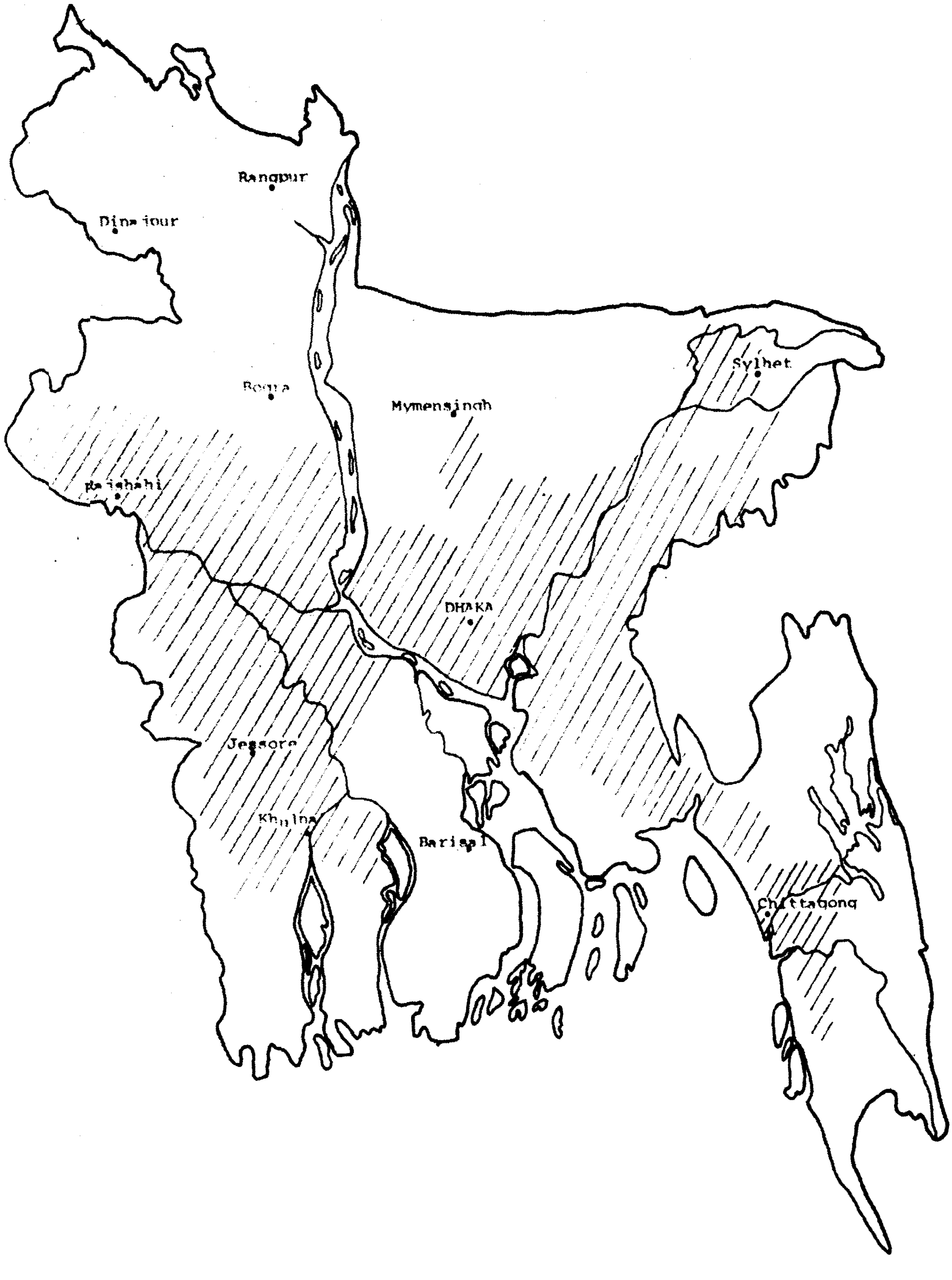


Fig. 8. Distribution of bamboo blight observed in Bangladesh as indicated by hatching.

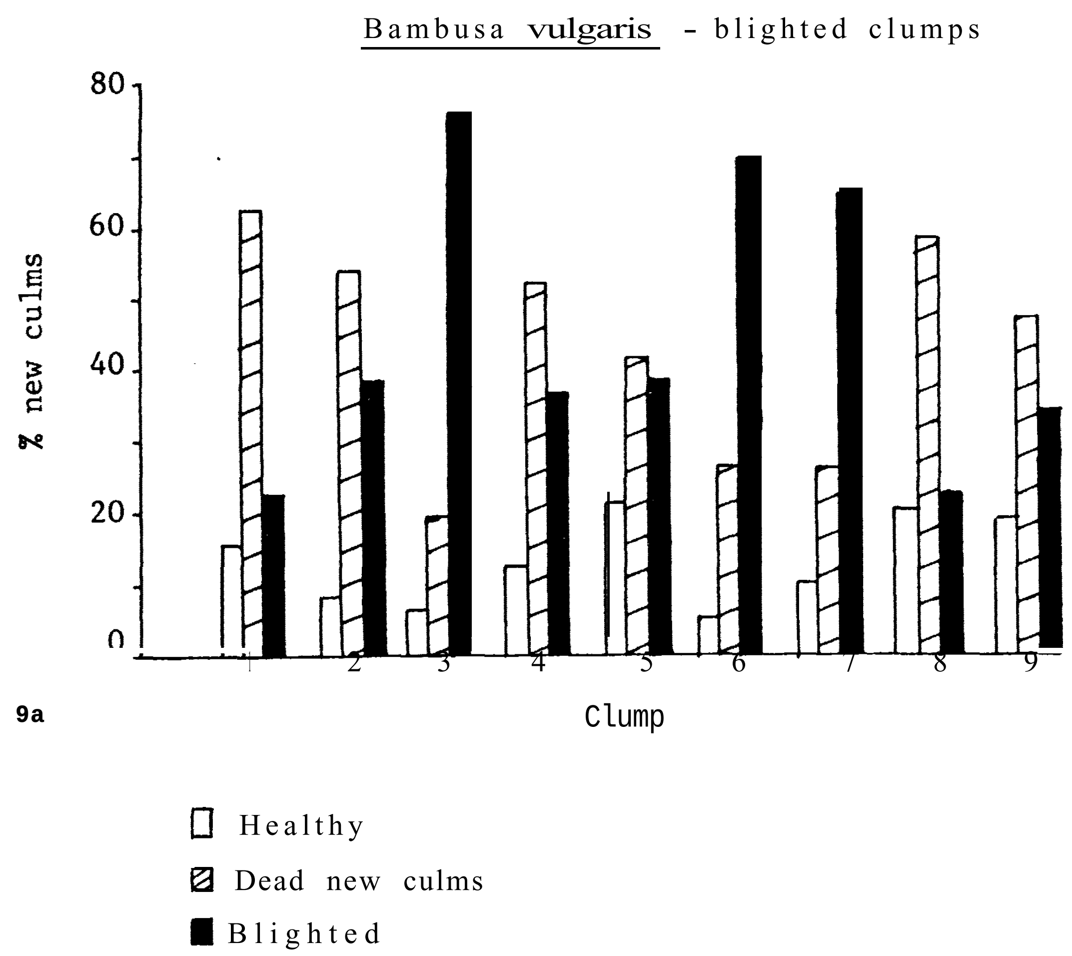


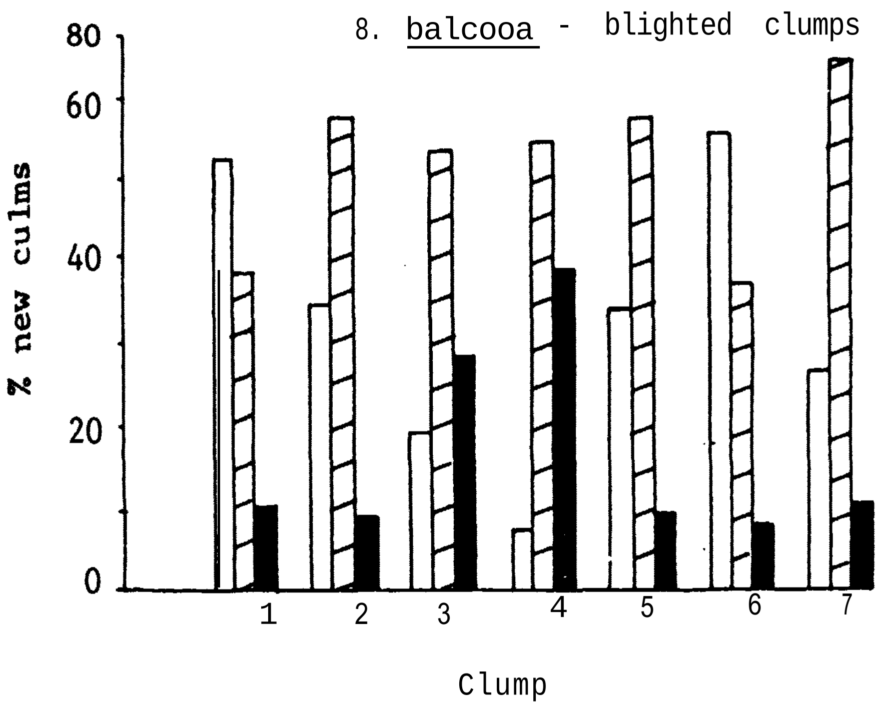
Fig. 9. The fate of new culms produced by healthy and blighted bamboo clumps in 1983: A) Bambusa vulgaris blighted clumps: B) B. balcooa blighted clumps; C) B. balcooa and B. vulgaris healthy clumps.

then no further development of blight symptoms although in following years new branches which develop (on the blighted culm) healthy portion may die back. A major source of loss in both healthy and blighted clumps is the failure of very young culms to develop (Fig. 9). This may be up to 60% of the new shoots in the case of blighted clumps of B. vulgaris. There was little difference in losses due to dead young culms in healthy and blighted clumps of B. balcooa. Ueda (1960) reported similar levels in healthy clumps of Phyllostachys spp in Japan. it is not clear whether the phenomenon of young culms failing to develop beyond a minimal height is therefore part of the bamboo blight disease syndrome.

What is the cumulative effect of blight on clumps over a period of years? Several of the clumps of B. vulgaris in Fig. 9 have died in either 1984 or 1985. Others will die in 1986. In all these clumps blight has been the main factor in their decline although the situation has been exacerbated by bad planning and over-cutting. In B. balcooa there is no direct indication that blight can kill clumps. Often the proportion of new shoots that become blighted in successive years remains more or less constant and the fact that culms grow to a much greater height before becoming blighted must contribute to the lessened effect of disease on the health of the clump. So far only anecdotal evidence and some indirect evidence (Fig. 11) exist to suggest that blight results in the death of some clumps of B. balcooa (Fig. 12)

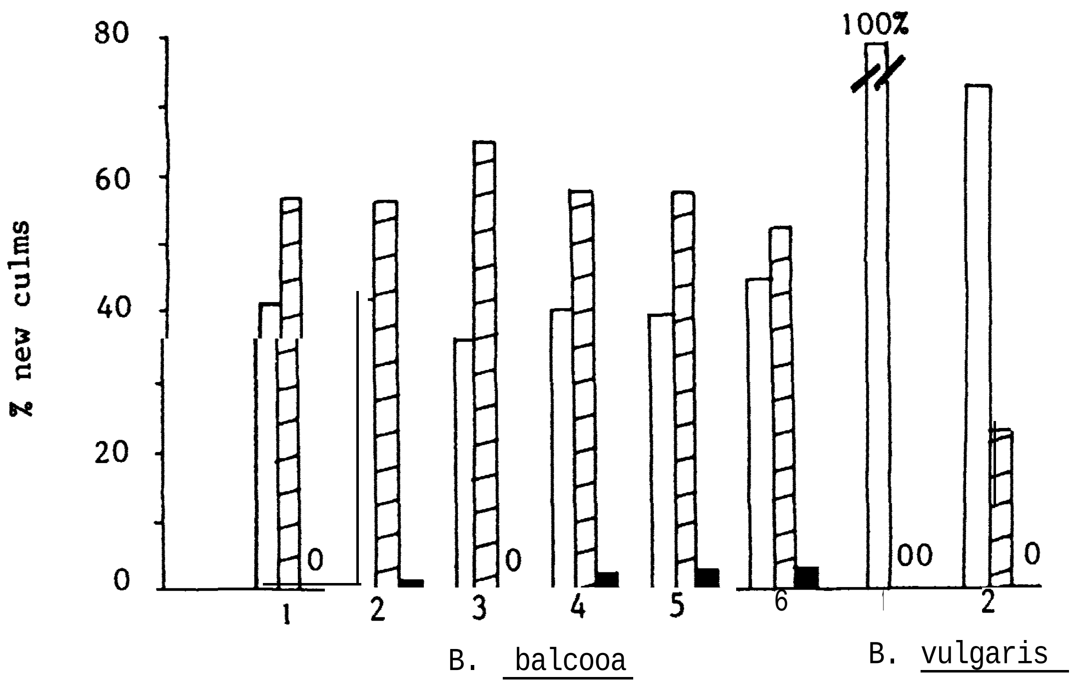
Isolation of Fungi from blighted and healthy Bamboos

Pieces of culm tissue were taken from the edge of blight symptoms and healthy culm tissue and placed on tap water agar (TWA)



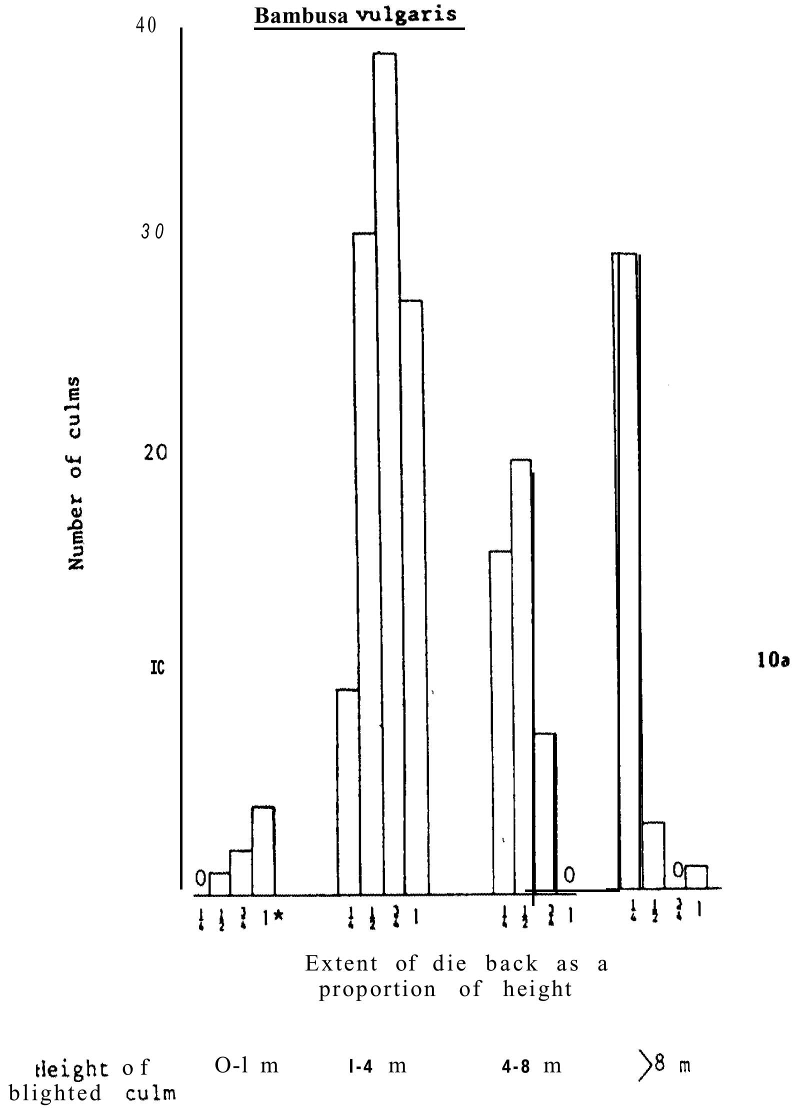
9b

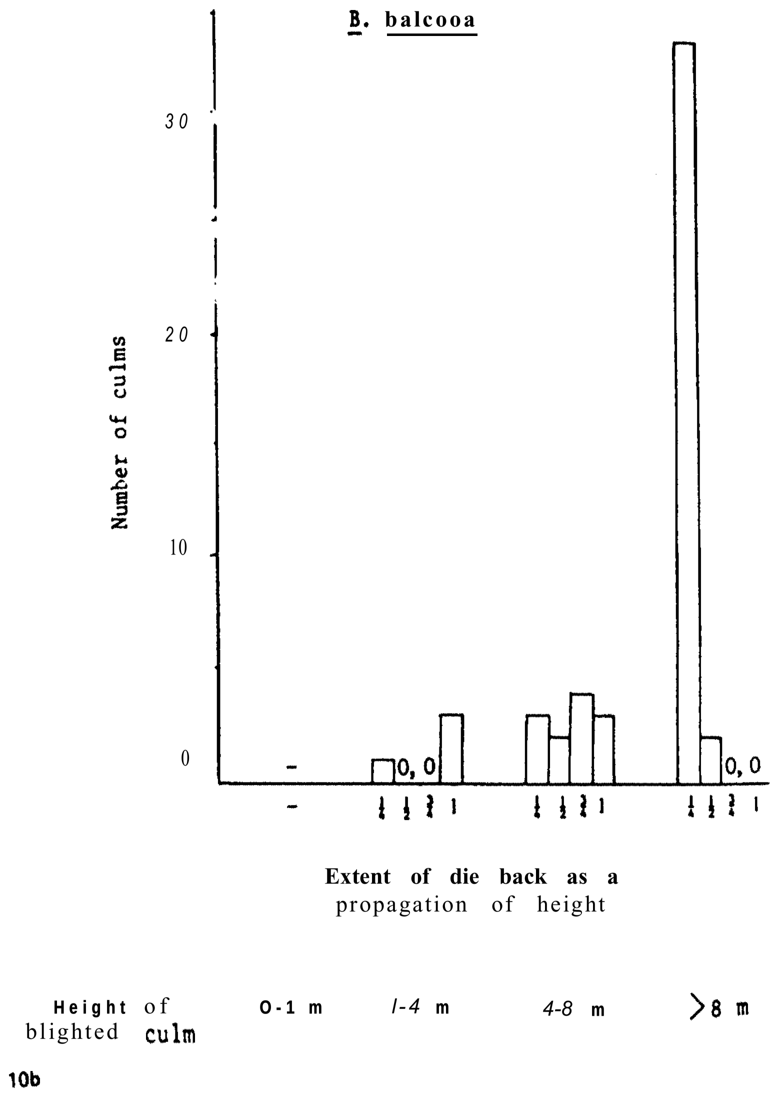
Healthy clumps



9c

Clump





*Dead

Fig 10 Final extent of die back in new culms of blighted clumps: A) *Bambusa vulgaris* (9 clumps); B) *B.* balcooa (7 clumps)

Fig, 11. Bambusa balcooa rhizomes dug up from clumps reportedly killed by blight in the Faridpur district; to be used for fuel in brick making,

(1.5% w/v) and incubated at 30°C, TWA restricted the growth of the faster growing saprobic fungi which were commonly isolated, including Coniothyriurn fuckelii Sacc., Fusarium spp. and *Pteroconium* and *Arthrinium* anamorphs of A. piospora spp.

lsolations from older blight symptoms: The first set of isolations were made from blight symptoms on 4-8 month-old culms (Figs. 3 and 6). The fungus which aroused interest was the hyphomycete *S arocladium oryzae* (Sawada) W. Gams and D. Hawks. (Bady, 1980). the sheath rot pathogen on rice (Shahjahan et al,, 1977), and was isolated from several clumps. S. *oryzae was* obtained from 68 out of all clumps of blighted bamboo (Table 2). In several of these clumps die back symptoms only were present and if a separate sample is taken from these clumps of 13 clumps of B, *vudgaris* and 15 clumps of B. balcooa. all of which showed internal staining and insect channels in addition to die back, then the recovery of S. *oryzae* increases to 100% and 85% respectively.

Isolations from young blight symptoms: In a follow-up series of isolations tissues with early symptoms were sampled. from culms that were only a week old to 2-3 months (Fig. 4). The recovery of S. oryzae from blight symptoms on such culms was much higher (Table 3). Table 4 gives details of the tissues sampled from blighted and healthy clumps and the results of S, oryzae recovery. *S. oryzae* sporulates freely on TWA and can be easily seen (x 50) under a dissecting microscope, even when other faster growing fungi are present. Conidiophores tend to be simple and unbranched on the original isolation plate, the typical branched aerial conidiophores (Brady, 1980) best being seen on potato carrot agar subcultures,

In both f3, balcooa and B. *vulgaris, S, oryzae* was almost always isolated from the black staining surrounding insect holes (Fig. 4). The range of fungi found in early and late infections stages was similar. How ever one fungus. tentatively identified as *Periconia* sp., was often isolated from young symptoms and was also seen to freely sporulate on the outer surface of dying culm sheaths both on blighted and healthy culms. In some cases only bacteria developed from young symptoms, particularly with samples from water soaked areas,

Fig. 12. Dying *Bambusa balcooa* culms sheath. Necrosis generally starts at top edge proper. Note hairs on sheath from which fungal isolations were made (see text for details).

Table 2. Isolation of Saroclудium oryzae from older blight symptoms (Figs. 2b, 3, 5) on 4-8 month-old culms

Species	Number of blighted clumps sampled .	Isolation of Sarocladium oryzae	
		Yes	No
Bambusa balcooa	51	30 (59%)	21
B. tulda s.l.	15	10 (68%)	5
B. vulgaris	40	25 (63%)	15
"JAWA" (local	5	3 (60%)	2
name – Bambusa sp.?)	5	3 (60%)	2
TOTAL:	116	71(61%)	45 (39%)

'One or two culms per clump were sampled.

Table 3. Isolation of Sarocbdium oryzae from young blight symptoms (Fig. 4) on 0-3 month-old culms and from O-3 month-old culms in healthy clumps

Species	State of clump	Number of clumps .	Isolation of *Sarocladium oryzae*	
			Yes	*No*
Bambusa balcooa	Healthy . '	9	8 (89%)	1
	Blighted	18	15 (83%)	3
B . vulgaris	Healthy . .	10	6 (60%)	4
	Blighted	13	11 (85%)	2

• One or two culms per clump were sampled.
• No die back or streaking was seen on any of the culms but insect holes and staining could be found in a few places only.

freely sporulate on the outer surface of dying culm sheaths both on blighted and healthy culms. In some cases only bacteria developed from young symptoms, particularly with samples from water soaked areas.

Where S. *oryzae* only grew from a sample it was described as "pure", and "mixed" when other fungi were present (as seen x 50 on TWA). About half the samples from black staining at insect holes were "pure"; even where "mixed" the growth of S. *oryzae* was still marked. "Pure" S. oryzae was also obtained from symptomless parts of the culm (Table 4) in blighted clumps. These parts included the compacted area of culm sheaths inside the growing culm apex and below this from the edge of the uppermost culm lumens (Fig. 7a). S. *oryzae* was also isolated from one apex of a completely healthy new culm in a blighted clump of B. *balcooa* and B. *vulgaris.*

Isolations from culm sheaths: The presence of S. *oryzae* on culm sheaths of healthy and blighted clumps was investigated. Both B. *vulgaris* and B. balcooa have hairy culm sheaths (Fig. 12) and these hairs were sampled by placing a few directly onto TWA. Isolations were also attempted from *surface* sterilised necrotic patches on the culm sheath itself. S. *oryzae* was isolated from these early necrotic patches on some of the culm sheaths sampled (Table 4), but several other fungi were always present as well, with only small areas of S. *oryzae* developing on the TWA.

Table 4. Isolation of Saroclaodium oryzae from O-3 month-old culms in blighted snd healthy clumps according to type of sample.

Origin of sample	Isolation of Sarocladium oryzae					
	Bambusa balcooa			B. vulgaris		
	No. of clumps	Yes	No	No. of clumps	Yes	No
a) Blighted Clumps						
1. Black staining around insect holes (Fig. 4)	14	13	1	9	8	1
2) Black staining extending into culm wall without insect damage (Fig. 4)	Not seen			7	6	1
3. Surface discoloration of culm (Fig. 4a)	3	3	0	9	1	8
4. Dying young culms (Fig. 7)	1	1	0	1	1	0
5. Culm sheath necroses (Fig. 12)	6	4	2	5	3	2
6. Insect larvae from 1	3	0	3	3	3	0
7. Tissue showing no sign of symptom development (see text and Fig. 7a)	5	2	3	8	3	5
b) Healthy Clumps						
1. Black staining around isolated insect holes occurring on a few culms only	4	3	1	6	4	2
4. Dying young culms	2	1	1	1	0	1
5. Culm sheath necroses	3	3	0	5	2	3

The amount of growth varied from small areas 1-2 mm in diameter to other instances in which it sporulated up to 15 mm away from the hairs. In a study of healthy bamboos growing in the north west, where no blight is present, S. oryzue was recovered from nine out of ten clumps of *B. balcooa* and three out of four dumps of B. tulda s.l. Isdations from associated healthy culm tissue were not attempted.

Acremonium strictum on bamboo: Rahman and Khisa (1983) reported the isolation of Acremonium stricturn from blighted bamboos, isolates of which were used in artificial inoculation experiments. These isolates have recently been re-examined at the Commonwealth Mycological Institute and shown to be S. oryzae. The two fungi are in fact very similar as shown by the descriptions given in Holliday (1980).

Comments on the causes of Bamboo Blights

Only limited artificial inoculations have been carried out with S. oryzae on bamboo, both by Rahman and Khisa (1983) and myself. Rahman and Khisa showed that S. oryzae (A. strictum as mistakenly reported – see above) produced a necrosis and resulted in the death of young branches, which showed a pattern of symptom development similar to that seen in the field. I inoculated fully extended internodes of 5 month-old culms by wounding and which in turn developed a black staining spreading above and below the wound. No die back occurred or streaking. S. oryzae was re-isolated from these symptoms, It is only recently that it has been shown that the first symptoms of bamboo blight occur on growing internodes and future artificial inoculations will concentrate on introducing S. oryzae to culm tissue at a similar stage. Cross inoculations are also planned with bamboo isolates of S. oyzue on riee and with rice isolates on bamboo to see whether we are dealing with exactly the same fungus or whether a separate pathogenic race has developed on bamboo. It is interesting to note that sheath rot of rice was first reported from Bangladesh at the same time as bamboo blight (early 1970s). S. oyzae is seedborne in rice (Shahjahan et al., 1977) and it is suggested that this is how the fungus was introduced to Bangladesh (Dr S Miah, Bangladesh Rice Research Institute, pers. comm.). The fungus is now found throughout Bangladesh on both diseased rice and blighted bamboo and even on the culm sheath hairs of healthy bamboos in blight-free areas. The extent to which S. oryzae is present on culm sheaths of healthy clumps in blighted areas has still to be examined.

How important is Bamboo Blight?

Bamboo blight must be considered a serious disease if only because it attacks the growing cuim, stops any further growth and produces a die back which may in some case kill the cuim completely. Even if this only happens in a few cuims of a season's growth this could represent a major loss to the farmer. The importance of the disease in clumps of B. balcooa varies; some clumps may show one or two clumps which develop blight each growing season whilst in other clumps most of the new cuims become blighted. The effect of the disease on B. vulgaris is more serious, and blight can kill clumps, especially when the already significant effects of blight are compounded by overcutting and badly planned cutting. Although the disease is not causing widespread damage throughout Bangladesh, as was feared might happen, it is a major problem in several areas. Concern about the disease should not, therefore, be allowed to wane. Blight may have decreased in some areas but it has become more of a problem in others. The disease is at present only found in Bangladesh but S. oryzae is a widespread pathogen on rice and occurs throughout Asia along with various Bombusa spp. Priority areas of research must be to fully examine the pathogenicity of S. oryzae on bamboo and also investigate the role of insects both in introducing the fungus into the culm and facilitating the spread throughout the cuim (and between clumps).

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Utilisation

The Role of Bamboo as a Potential Food Source in Thailand

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Abstract

This paper summarises the information on *bamboo shoot production in Thailand, the main components and food value of bamboo* shoots, possible increase *in* production for *the next five years, and potential economic benefits.*

Introduction

Thailand's total area is 513,115 km^2. The country is located in Southeast Asia, between the latitudes 5° and 21°N and the longitudes 97° and 105°E. The humid tropical climate is influenced by seasonal monsoon and the local topography. The forest types are varied, with rich flora ranging from tropical evergreen forests on the Peninsula to dry, deciduous, dipterocarp forest scattered in the northern, central and northeastern parts of the country. The species of bamboo in Thailand are abundant including 12 genera and 41 species. Bamboos grow naturally as scattered undergrowth in all forest types throughout the country. There is only one area where bamboos are found as pure stands, in Kanchanaburi province, about 200 km west of Bangkok. In Thailand, bamboos are used for a variety of purposes, including food, household construction, supporting poles, pulping, basketry and other handicrafts.

The Sprouting of Bamboo

Bamboo shoots develop from rhizomes during the rainy season. The buds on rhizome-nodes enlarge for several months in the soil. The shoots emerge out of the ground in the form of tender, pointed cones covered with imbricate sheaths inserted at the nodes. These shoots then elongate rapidly, and after one month they will develop into mature woody culms. The number and period of sprout-emergence out of the ground vary according to the species, the size and vigour of the clump, and also the environmental condition of the locality. It varies from 50 to 60 days between early and late-sprouting. The sprouting is strongly influenced by rain in May and June. An investigation on bamboo sprouting was carried out during the rainy season in 1970 (Watanabe, 1972) with results shown in Table 1.

Nutritive Value of Bamboo Shoot as Food

The young and tender shoots of most of the edible bamboo species are consumed fresh or made into pickles, vegetables and

Table 1. Period of bamboo sprouting.

Species	Beginning	Ending	Period (days)
Bambusa arundinacea	May 10	June 25	46
Bambusa vulgaris	May 1	June 22	52
Bambusa tulda	May 25	June 27	33
Thyrsostachys siamensis	May 15	June 1	47

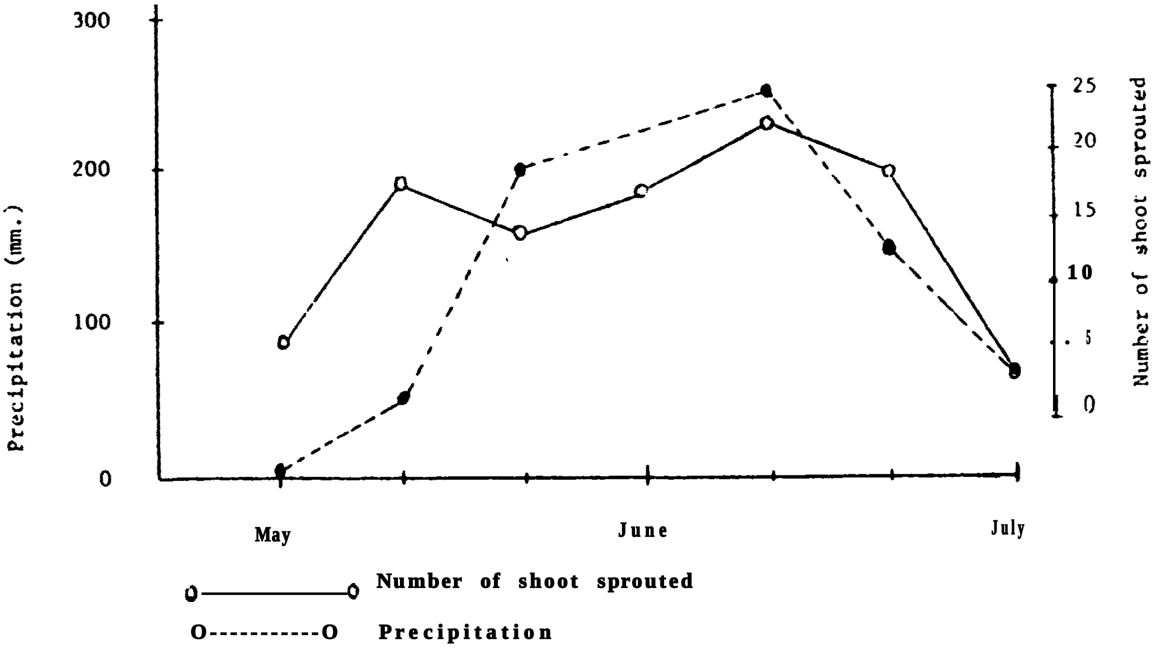

Fig. 1. Relationship between the number of bamboo sprouts emerged out of the ground and the precipitation.

dried forms that are considered delicacies.

Quantities of shoots at three ages (7, 10 and 15 days after emergence) have been studied (Tamolang et al., 1980). The nutrient components such as protein, fat, ash, total carbohydrates, crude fiber, calcium, phosphorus, iron, thiamine (Vitamin Bl) and ascorbic acid (Vitamin C) were chemically analysed. Results showed that age has no relationship to nutrient contents. The shoots were made up of more than 75% water.

The contents of nutrients in bamboo shoots vary according to the different parts of the bamboo sprout. The soft tissue, close to the apex, contains less coarse fibers and are protein rich. The lower parts, especially the portion where the sheaths were peeled off, contain less protein and more coarse fibers. Results of a study of nutrient components of Phyllostachys edulis sprout were reported (Resources Bureau Reference Data No. 34, 1960) and are given in Table 2:

Bamboo for Food Production

Young and tender bamboo shoots are used as daily food for Thai people because of its good taste and low cost. The shoots are highly nutritious, palatable and can be cooked and prepared in many delicious ways. Most bamboo sprouts consumed are harvested from natural forests. Only one species comes from commercial plantation of Dendrocalamus asper, which appears to top the list of edible bamboo species. The edible species of bamboo in Thailand commonly used for food are as follows:

1. Pai Tong – ***Dendrocalamus asper***
2. Pai Seesuk – ***Bambusa blumeana***
3. Pai Ruak – ***Tbyrsostachys siamensis***
4. Pai Ruakdam – ***Thyrsostachys oliverii***
5. Pai Bong – ***Dendrocalamus brandisii***
6. Pai Sangdoi – ***Dendrocalamus strictus***
7. Pai Rai – ***Gigantochloa albociliata***

Besides local consumption, bamboo shoots are also exported. (Table 3).

Table 2. Analytical results of bamboo sprouts (per 100 g fresh matter).

Nutrient	Fresh matter	Canned food
Crude protein	2.5 g	1.9 g
Crude fat	0.2 g	0.1 g
Carbohydrates – Sugar	2.9 g	2.9 g
– Crude fiber	1.0 g	1.8 g
Water content	92.5 %	92.8 %
Calorie.	23 cal.	20 cal.
Ash	0.7 g	0.4 g
Lime	1 mg	1 mg
Phosphorus	43 mg	26 mg
Iron	7 mg	1 mg
Vitamin – A	50 i.u.	50 i.u.
– B_1	0.10 mg	0.05 mg
– B_2	0.08 mg	0.05 mg
– C	10 mg	0 mg

Table 3. The export of bamboo shoots of Thailand.

Types \ Year	1983		1984		1985	
	Quant. Tons	Value. US$	Quant. Tons	Value. US$	Quant. Tons	Value. US$
1. Fresh, chilled bamboo shoots	288.8	222,821	338.9	382,062	238.5	165,873
2. Dry Bamboo shoots	29.7	129,182	15.2	48,332	–	–
3. Canned bamboo shoots	5,864	3,030,309	8,557	3,406,347	–	–

Source: Department of Business Economics, Ministry of Commerce, Bangkok, Thailand.

It is difficult to obtain accurate information on the real consumption of natural bamboo shoots, since there is no restriction for collection of bamboo shoots from forests. The original bamboo plantations are mainly in Prachin Buri Province, 120 km east of Bangkok, and others were subsequently established successfully in every part of the country. The agricultural areas converted to plantations of Dendrocalamus asperare 6,000 ha at present and expected to double to 12.000 ha by 1991.

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The Changes in Nutrient Composition of Bamboo Shoots at Different Ages

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Abstract

The moisture content of bamboo shoots of three different ages increases gradually with age, *and finally averages* at about 92%. The rough fibers also increase with age, as the ***tissue grows old. In contrast, the nutrient composition such as protein, amino-acids, fat, carbohydrate, other minerals. inorganic salts etc., decrease with age. Therefore, the right time to gather the spring bamboo shoots is*** when they ***are still underground. It will certainly affect the*** quality **of** ***bamboo shoots if the gathering time is prolonged.***

Introduction

Phyllostachys ***pubescens, also*** called Mengzong Bamboo Shoots is China's bamboo. They are cultivated extensively for their shoots. China's output of these shoots is the highest in the world. The quality of bamboo shoots largely depends on the number of days after the sprouts' appearance on the ground which is also taken as the age of bamboo shoots. Both qualitative and quantative analyses of the nutrient composition of bamboo shoots are made to provide scientific basis for the gathering time of quality shoots. Better quality shoots fetch higher prices.

Samples and Methods

On April 4, 1984, in the bamboo groves of Wuxing Village, Miaoshan Township in the suburbs of Ningbo, Zhejiang Province, 23 bamboo shoots, the sheaths of which appeared on the ground, with the sprouts still underground, were selected as samples for analysis. On that day, five shoots were gathered and the others were marked, which were subsequently gathered once every five days, seeing to it that they were almost of the same size. At first collection, the average shoot length was 19.53 cm and the perimeter was 20.37 cm. On April 9, the second collection, the average length and perimeter were 25.23 cm and 20.74 cm and during third collection the averages were 36.41 cm and 2 1.06 cm respectively.

The gathered shoots were transported to laboratory in refrigerated flask. They were peeled instantly and the unedible part was cut off with a stainless steel knife. In order to do away with individual differences as much as possible, each shoot was first cut vertically and then horizontally, forming small squares. These squares were thoroughly mixed and 500 g was taken as samples. Of this, 20 g was dried at 10°C in an oven for 20 minutes, fresh samples were used for analysis of moisture content. The other samples were then dried at 80°C in a drier. The dried samples were ground into powder and stored in bottles for further use.

Methods of analysis: 1. Protein was determined by K's nitroimetric analysis. 2. Amino-acids were determined by Hitachi 835-50 Model amino-acids auto-analysis instrument. The qualitative and quantitative analyses were made of protein- hydrolysate amino-acids. 3. Fat was determined by residues. 4. Sugar and soluble sugar were determined by colorimetric analysis. 5. Fibers were determined by acid-alkali analysis. 6. Ash content was analysed by dry ash determination. 7. Phosphorus was determined by anti-calorimetric analysis of Molybdenum and antimony. 8. Calcium and iron were determined by atom-absorption spectrometric analysis. 9. Moisture content was determined by drying at 105°C in an oven. lg of carbohydrate produces 4,000 calories;

1 g of fat produces 9,000 calories; 1 g of protein produces 4,000 calories. 11. Vitamin C was substracted with 1% oxalic acid and determined by titrimetry of 2.6

Except the data for amino-acids, the data for other items are the averages of the three analyses. In order to compare the present data with other vegetables, the data are converted into percentage of fresh bamboo shoot weight.

Analysis and Results

The changes of protein and amino-acids: The bamboo shoots of the three different ages (one with sprouts underground, another with sprouts appearing on the ground five days, and still another with sprouts appearing on the ground ten days), have a high content of protein, higher than any other varieties of vegetables. However, protein decreases with age; every five days, the protein is reduced by 11.7% to 3.7% (Fig, 1)

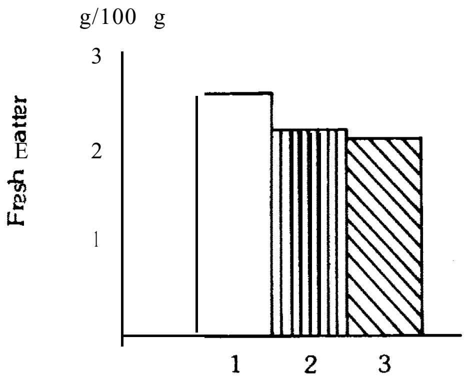

Fig. 1. The changes of protein in bamboo shoots of the three different ages.
(1) Sprouts underground.
(2) Sprouts appearing on the ground 5 days.
(3) Sprouts appearing on the ground 10 days

The bamboo shoots of the three different ages contain 18 varieties of protein hydrolysate amino-acids. They are ASP, THR, SER, GLU, GLY, ALA, CYS, VAL, MET, ILE, IEU, TYR, PHE, LYS, NH^{3}, HIS, ARG, PRO, etc. (See Fig. 2, a.. .r indicate the peak amount of various amino-acids).

From part of the data shown in Fig. 2, we got Chart I. The bamboo shoots of the three different ages contain the highest amount of TYR, almost accounting for 3.51% of the weight of the dried bamboo shoots, which increases with age. TYR amounts to 4.8% in the bamboo shoots ten days after the sprouts appeared on the ground. That is unfavourable for bamboo shoots processing and canning for it produces some white **coaguia,** greatly affecting the quality of boiled bamboo shoots. Besides TYR, GLU and ASP are also rich; their content decreases with age. Young bamboo shoots of small size is delicious because they are rich in GLU. The content of PRO, IEU and ALA amounts to over 1% respectively, that of the former decreasing with age while that of the latter, though varying, a little, remaining almost stable. Nutrients contained in bamboo shoots are CYC and HIS, which are stable, too. The total content of amino-acids decreases with the age of bamboo shoots.

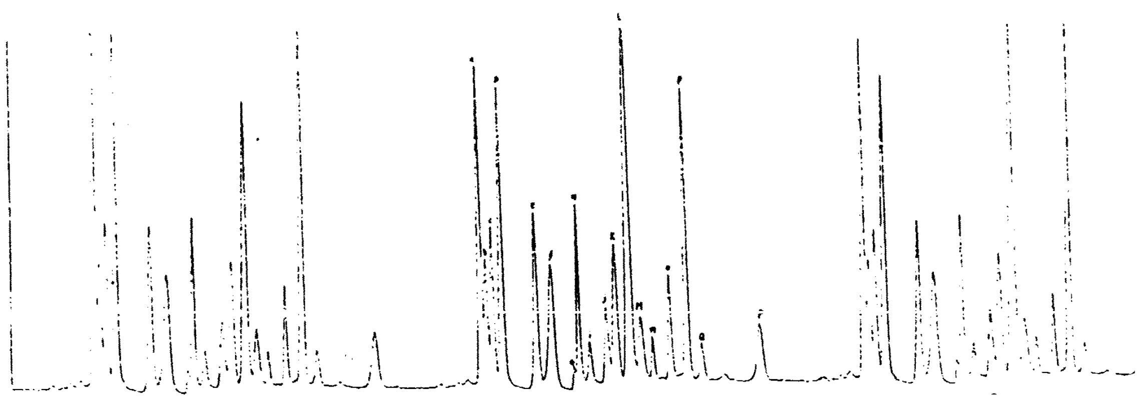

Fig. 2. The changes of amino acids in bamboo shoots of the three different ages

Table 1. The changes of amino acids in bamboo shoots of the three different ages (per 100 g dried matter).

Portion	sprouts underground	Sprouts appearing on the ground 5 days	10 days
ASP	3.31474	2.42582	2.54518
THR	0.72376	0.75652	0.70892
SER	0.79628	0.79064	0.71882
GLU	3.22632	2.71544	2.7336
GLY	0.7221	0.77014	0.71612
ALA	1.12158	1.1923	1.05694
CYS	0.22232	0.20068	0.22068
YAL	0.947	1.0026	0.91458
MET	0.3095	0.35472	0.29906
ILE	0.63158	0.70166	0.61968
LEU	1.13114	1.24632	1.10554
TYR	3.51496	4.8589	4.81126
PHE	0.70734	0.81078	0.73556
LYS	0.64868	0.68206	0.52818
NH_3	0.69698	0.52746	0.7234
HIS	0.30132	0.32292	0.28432
ARG	0.89742	0.92424	0.79932
PRO	1.2212	0.7913	0.5865
Total.	21.13422	21.0745	20.10766

The changes of fat in bamboo shoots of the three different ages: Though very little, fat is richest compared with the fat content of other varieties of vegetables. Fat increases progressively with the age of bamboo shoots though the change is very little (See Fig. 3).

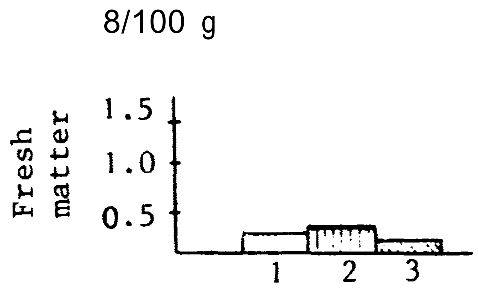

Fig. 3. The changes of fat in bamboo shoots of the three different ages.

The changes of carbohydrate in bamboo shoots of the three different ages: Carbohydrate in bamboo shoots include sugar, soluble sugar, rough fibers, etc. For the content of sugar, soluble sugar and rough fiber, see Fig. 4. With age, sugar and soluble sugar increase by 13.3% to 17.0% in five days and by 26.6% to 32.2% in ten days. Five days after the sprouts' appearance on the ground, the rough fibers increase by 14.6%, and ten days by 18.8%. The tissue grows older and gradually becomes inedible.

The changes of moisture content and quantity of heat in the bamboo shoots of the three different ages: The analysis shows that moisture content in the bamboo shoots of the three different ages increases with age (90.83% – 91.72% – 92.05%) till it reaches a period of steadiness. In contrast, the quantity of heat decreases

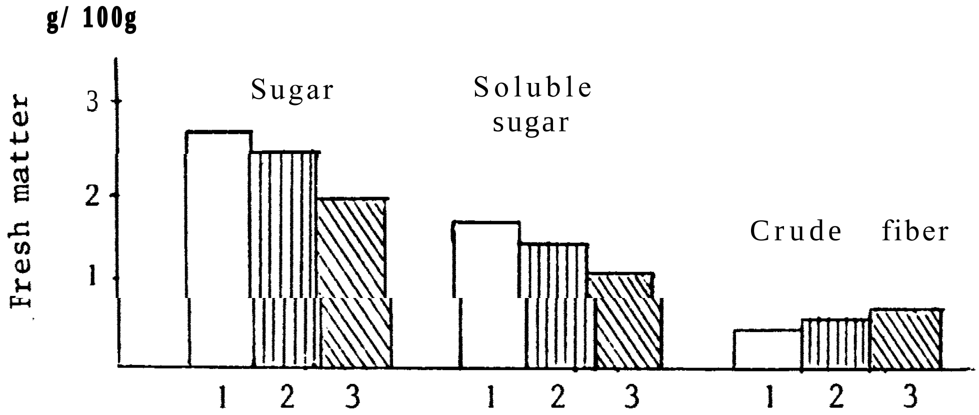

Fig. 4. The changes of carbohydrate in bamboo shoots of the three different ages

progressively with age (23.56% 21.05% – 18.7 1%) . In terms of the structure of quantity of heat (energy) bamboo shoots are relatively rich with nutrients (Fig. 5).

The changes of inorganic salts in the bamboo shoots of the three different ages: Bamboo shoots are rich in ash content with the average of 0.74 g in 100 g of fresh samples. The changes in ash content are little (from 0.73% to 0.75%) with age. Phosphorus and calcium decrease by 16.0% and 37.5% respectively five days after the sprouts' appearance on the ground, and by 25% and 43.8% respectively ten days after the sprouts' appearance on the ground. Iron steadies between 0.29 mg to 0.44 mg (See Fig. 6).

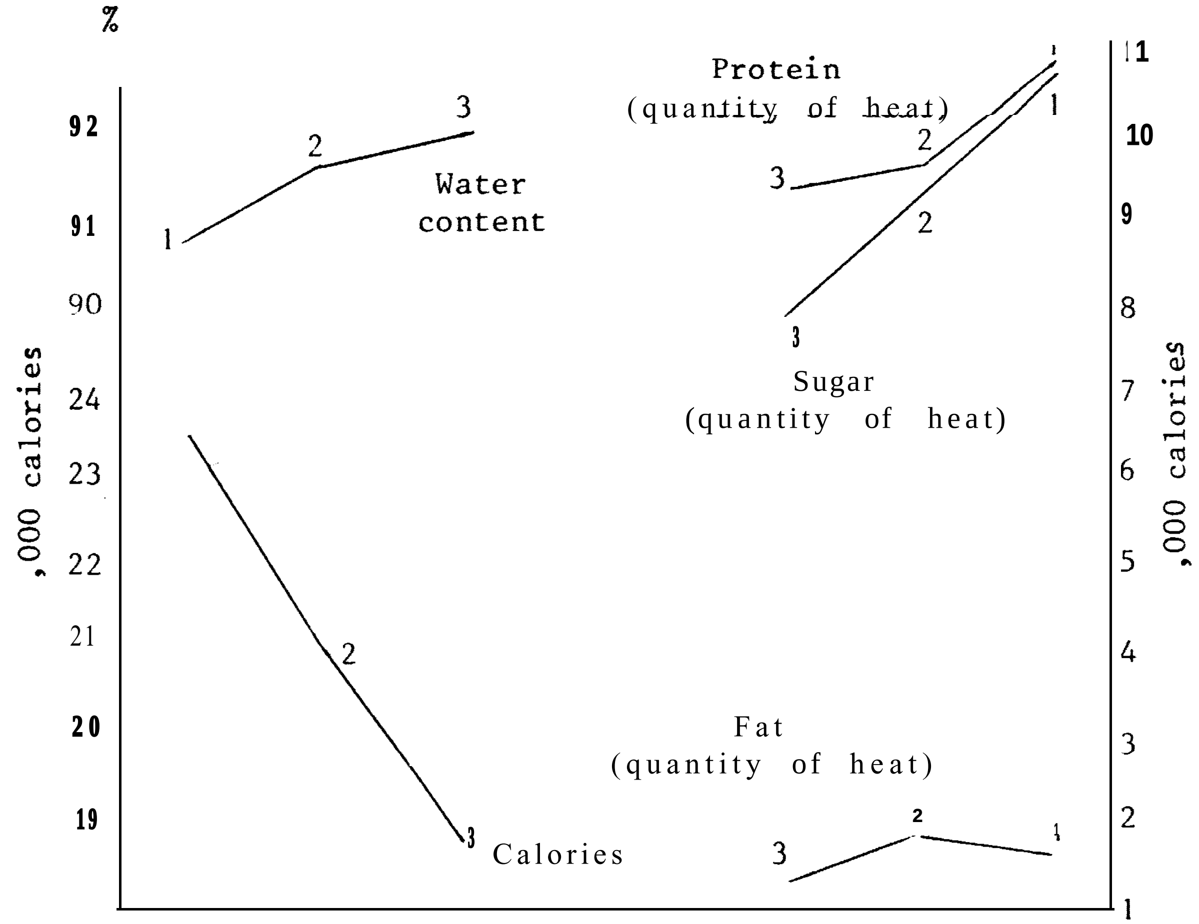

Fig. 5 The changes of moisture content and quantity of heat in the bamboo shoots of the three different ages

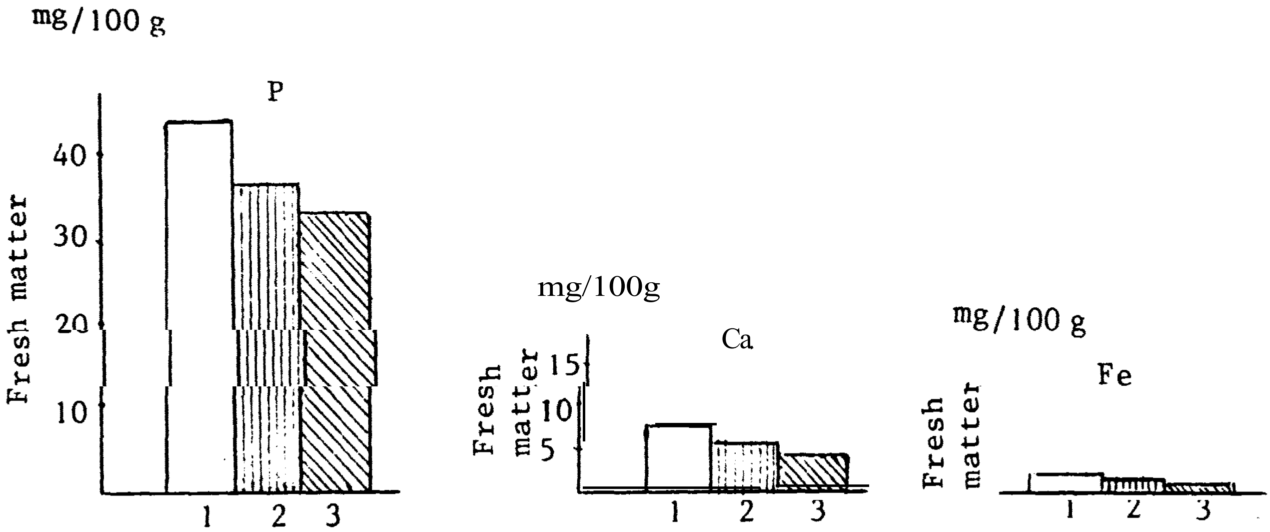

Fig. 6. The changes of inorganic salts *in* the bamboo shoots of the three different ages.

Vitamin C and other nutrient contents are very little, accounting for about 0.001% in the iced bamboo shoots.

Conclusions

The above analyses show that bamboo shoots are nourishing vegetables. With the age of bamboo shoots after the sprouts' appearance on the ground, moisture content increases slowly till it steadies at about 92% Rough fibers increase with age, and as a result, the tissue grows old, and the bamboo shoots become inedible. In contrast, protein, amino-acids, fat, carbohydrate, quantity of heat and inorganic salts, etc., decrease variably with the age of bamboo shoots. Therefore, in terms of nourishment, it is wrong to put off the gathering time of bamboo shoots, which results in higher output but of poor quality. In terms of processing, early gathering of bamboo shoots results in high quality though lower output. In particular, the increase of white coagula greatly affects the quality of boiled bamboo shoots. Therefore, it is the right time to gather bamboo shoots when they are still underground with sheaths just appearing on the ground. Quality deserves greater attention for bamboo shoots which are to be eaten fresh or to be canned. In recent years, there appears a tendency in certain places in the countryside to put off the gathering time for bamboo shoots. That raised the output a little, but greatly lowered the quality of bamboo shoots. The edible parts becoming less, suitable for canning and suitable only for drying.

The following three references give additional information. •

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Characterization of Steam-Exploded Bamboos for 'Cattle Feed

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Abstract

By steam-explosion process bamboos such as Mosochiku (Phyllostachys pubescence) and Chishimazasa (Sass kurilensis) were converted to easily hydrolyzable materials *(EXBs) by cellulase, and the EXBs were digested* remarkably *by the ruminants. The* different *values were as follows: Saccharification, 95% and 87% of cellulose of the respective EXBs, and in vitro* digestibility of *the* Mosochiku *EXB, 50% of dry matter (DM). These values are comparable to those* of exploded *wood (EXW)* of white *birch (Betula platiphilla and better than* those of Japanese larch (Larix leptolepis) *EXW. The results* indicated that *the* utilization of bamboos *for cattle feed and fermentation are* promising *by the steam-explosion process.*

Introduction

Wood including bamboo is by far the most abundant biomass on earth, and it can be endlessly renewed. The need to develop renewable alternatives to petroleum, and to meet the world's growing requirements for fuel and food are important. However, because of chemical and structural heterogeneity the wood conversion process is still not economically feasible. Wood is a composite material composed of cellulose. hemicellulose and lignin, and that cellulose is embedded in a matrix of lignin-hemicellulose complexes. Papers on the conversion of wood to ruminant feed are published (Jackson, 1977; Klopfenstein, 1981). It is known that for enzymic saccharification and digestion of wood by ruminants, delignification or cleavage of the lignin-carbohydrate linkages is a prerequiste. (Tsao *et al.,* 1978). We have investigated the steam-explosion of woods and bamboos to accomplish economically feasible separation of cellulose, hemicelluloses and lignin of woody materials for chemicals, pulp and enzymic saccharification (Tanahashi, 1983; Tanahashi and Higuchi, 1983; 1985; Tanahashi *et* al., 1983). This paper reports on the enzymic saccharification and ruminant digestion of the steam-exploded bamboo (EXB).

Materials and Methods

Chemical analysis of bamboos: The culms of Mosochiku *(P hyllostachys pubescence)* and Chishimazasa . (Sasa kurilensis) were pulverized to 60-80 meshes and analyzed by a standard wood analysis method.

Preparation of steam-exploded bamboos (EXBs): Chips (500g. ca. 30 mm x 20 mm x 15 mm) of Mosochiku and Chishimazasa were treated with saturated steam at 28kg/cm^2, about 230°C for 1, 2.4.8 and 16 mins. Then steam pressure was instantaneously released to the atmospheric pressure via a ball bulb to give the EXB. White birch *(Betula platiphilla).* Japanese larch **(Laix** *leptolepis)* and rice straw were exploded at a similar condition. For the enzymic saccharification and determination of *in vitro* digestibility, wet EXB and EXW were freeze-dried and milled by a Willey mill with 1 mm meshes filter.

Saccharification of EXBs and EXWs with cellulase: Two hundred mg of freeze-dried EXBs. EXWs. and untreated bamboo and wood powder (40 meshs pass 80 meshes on) were subjected to *Trichoderma* cellulase

(Meicelase 8000 units, kindly donated by Meiji Seika Co.) digestion in 10 ml of acetate buffer (OIOZM, pH 5.0), at 40°C for 48 hrs by using a Monod-shaking incubator. After enzymic hydrolysis the sample was heated in a boiling water bath for **1** min and filtered. One ml of the filtrate was diluted to 100 ml and the total reducing sugars or glucose was determined according to Somogi-Nelson method or by a glucose analyzer.

in vitro Digestibility ofEXBs and EXWs: Freeze-dried EXBs, EXWs, untreated bamboo and wood powder were analyzed for dry matter (DM), organic matter (OM), crude protein and fat by the standard method. Separately, EXBs and EXWs were treated with a pronase solution and separated to insoluble cell wall structural fraction (CW) and soluble fraction according to the Abe's method (Abe et al., 1979). In vitro digestibility of EXBs and EXWs was measured by treating the samples with a mixture solution of the stomach juice of a sheep and an artificial saliva of McDougall at 38°C under CO_2 stream for 48 hrs. After the treatment the sample was centrifuged and treated with the pronase. Then, DM, OM, and OCW were determined, and in vitro digestibility of the respective fractions was calculated (Togamura et al., 1983).

Results and Discussion

Chemical composition of bamboos used in the present investigation is shown in Table 1. Cellulose contents of both bamboos were about 50%. Fig. lA-D shows scanning electron micrographs of the fibers of white birch EXW (Tanahashi et al., 1983). Vessels (a), fibers (b) and amorphous substances (c) are seen in Fig. lA. Most of vessels were destroyed to small fragments. Fibers suffered from some damage as a buckling (Fig. IA-D), a cleft along the fiber axis (Fig. 1B) rupture at the middle of a fiber (Fig. lC), expansion in a dome shape (Fig. 1D). The appearance of EXBs was similar.

Mosochiku and Chishimazasa EXBs, and EXWs of white birch and Japanese larch were subjected to enzymic hydrolysis using a Trichoderma cellulase (Meicelase). The results are shown in Figs. 2 and 3. Untreated wood and bamboo powder gave less than 5% saccharification with the enzyme, whereas Mosochiku EXB, Chishimazasa EXB and white birch EXW gave 59%, 44% and 68% saccharification, corresponding to 95%, 87 % and 98% of cellulose of the samples, respectively. However, Japanese larch EXW (28kg/cm^2, 4 min) gave 37% saccharification. The poor saccharification of the larch EXW with the cellulase could be ascribed to anatomical differences of wood, higher Iignin content, and structural differences of lignin. Coniferous woods are composed of mainly tracheids, and the lignin is composed mainly of guaiacyl lignin which is more condensed than guaiacylsyringyl lignin in hardwoods and grasses. However, we recently found that pretreatment of electron beam irradiation of conifer wood chips or after ball milling of conifer EXWs gave almost the same saccharification as in hardwood EXWs (Tanahashi and Higuchi, Unpublished data). Hence, it was indicated that EXBs and white birch EXW were suitable for enzymic saccharification and ruminant feed.

in vitro Digestibility of EXBs and EXWs: Bamboo, wood and rice straw contain large amounts of cellulose and hemicellulose but are low in values as ruminant feed, because of their low digestibility due to physical and chemical linkages between polysaccharides and lignin in the materials. However, by steam-explosion these linkages were cleaved and these materials were converted

Table 1. Chemical composition of bamboos

	Ash	Hot-water	Solubility in 1% NaOH	Alcoholbenzene	Cellulose	Pentosan	Lignin
	(%)	(%)	(%)	(%)	(8)	(%)	(%)
Mosochiku	1.3	20.0	32.2	4.6	49.1	27.7	26.1
Chishimazasa	1.9	13.1	38.7	9.2	52.3	25.0	19.4

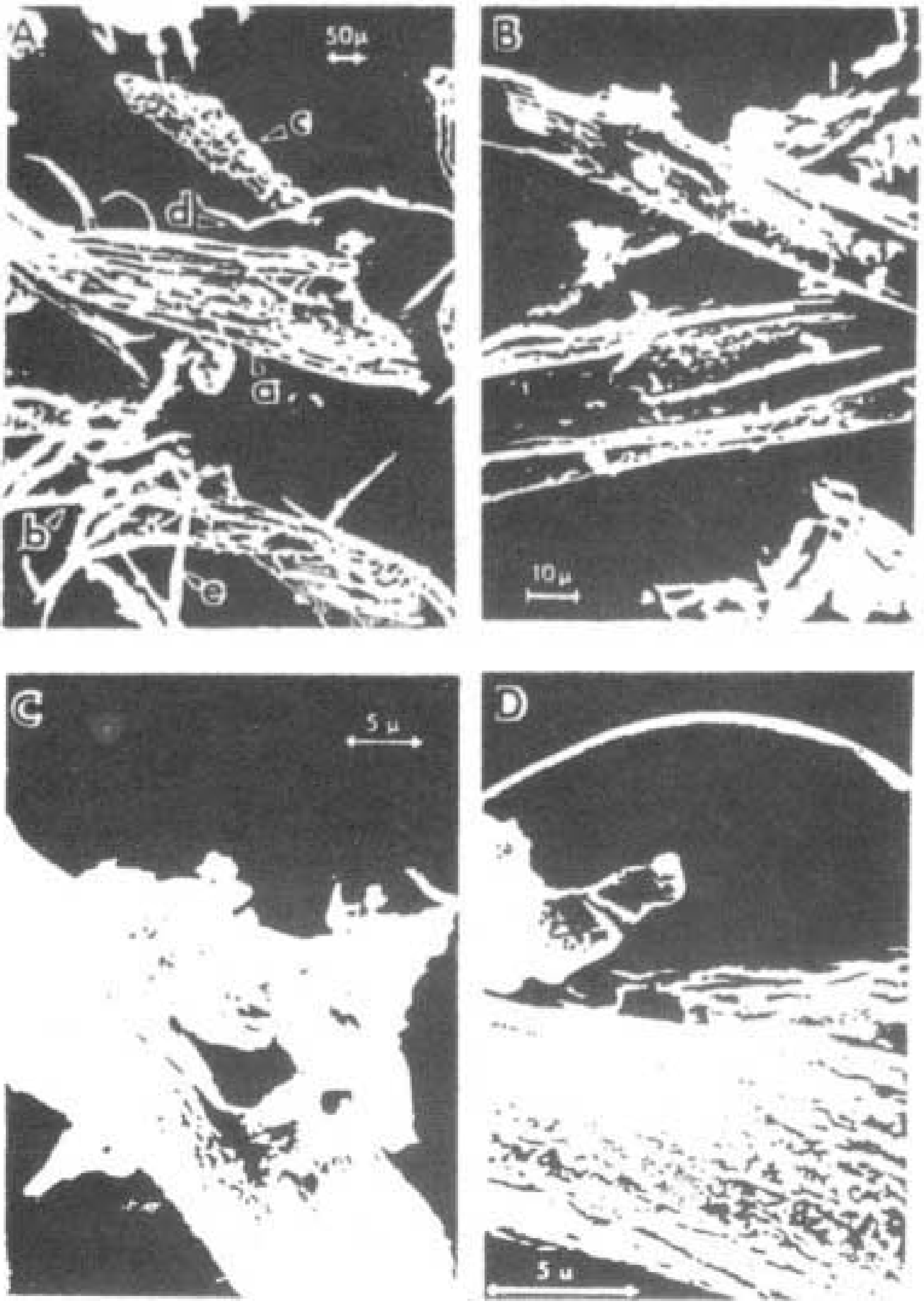

Fig 1 Photographs of white birch EXW (28 kg cm^2, 2 mm 1 (Scanning electron microscope

A, (a) vessels, (b) ftbers, (c) arnorphous substance. (d) buckling and (e) exponslon of a fiber

B, a cleft along a fiber

C. explosion of a fiber

D, expansron

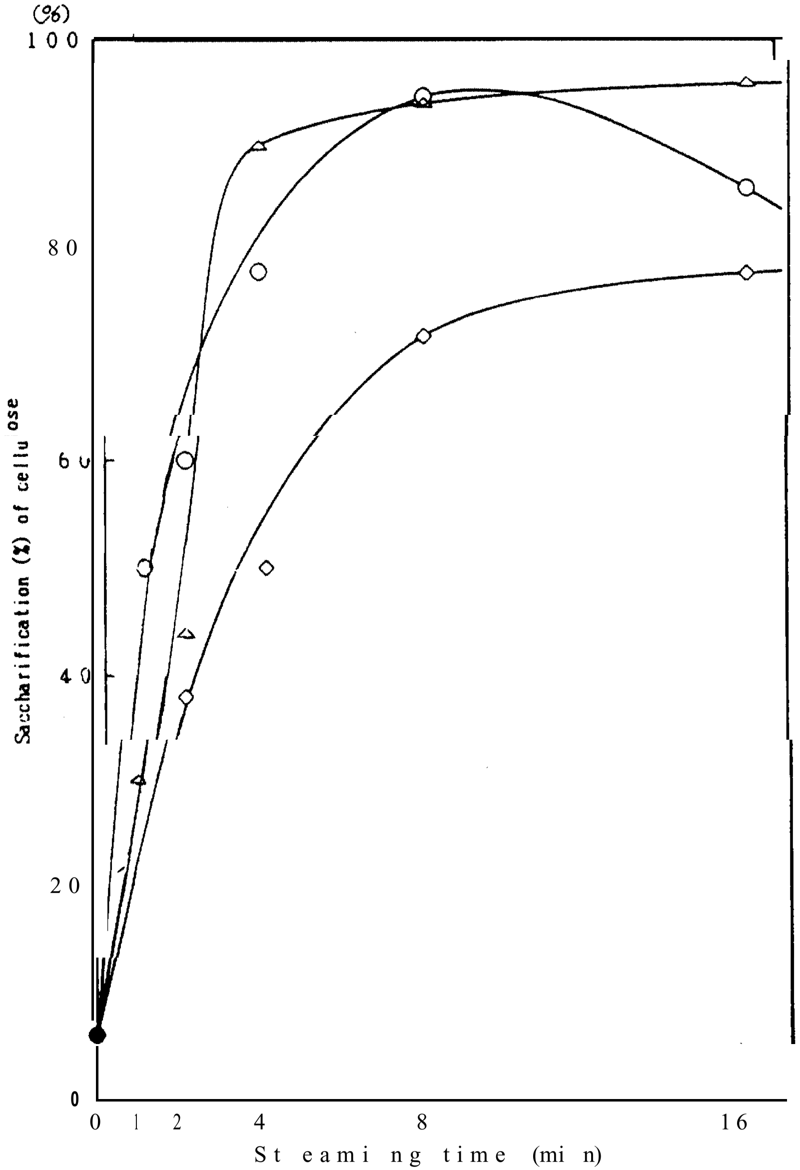

Fig 2 *Saccharification* (%) of cellulose of Mosochiku *EXB*

0 : steam pressure, 28 kg/cm^2
Δ : *steam pressure. 24 kg/cm2*
0 : steam pressure. 20 kg/cm2
● *unexploded bamboo powder*

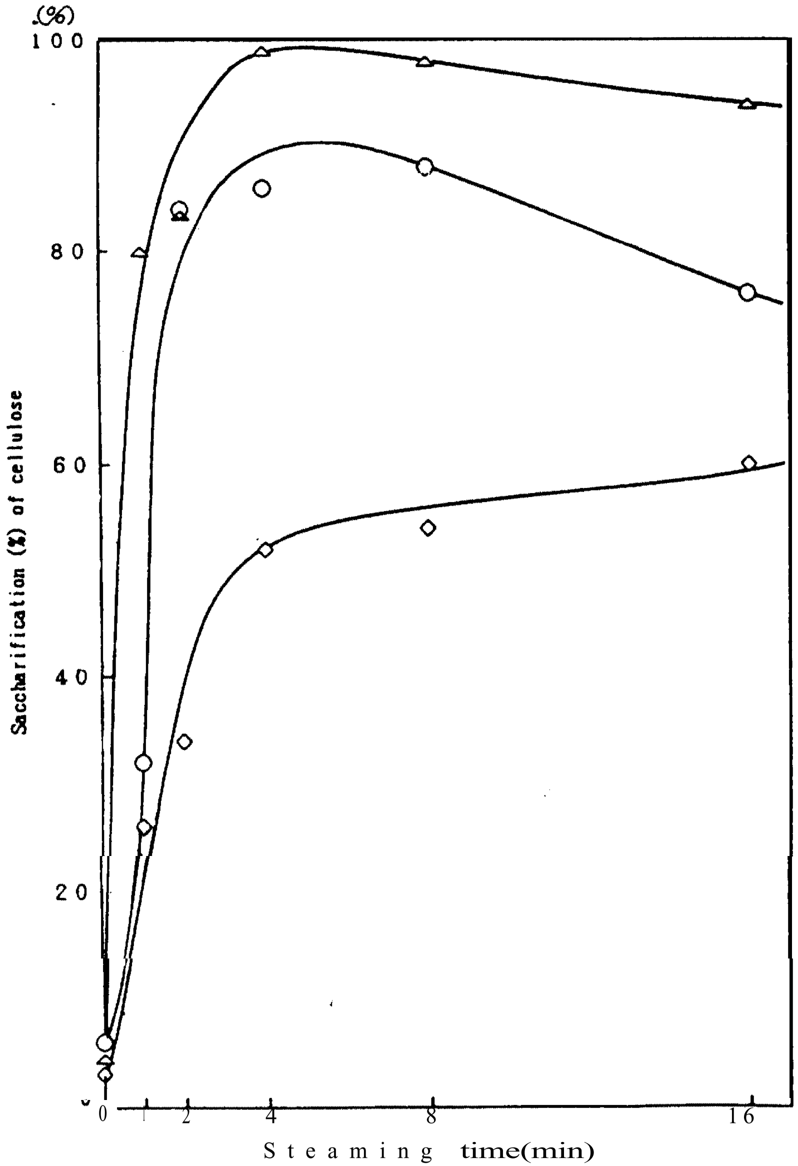

Fig. 3 Saccharification **(%) of cellulose of exploded materials**

O : Chishimazaso (steam pressure, 28 kg/cm2)
A . white birch (steam pressure, 28 kg/cm2)
0 : *Japanese larch (steam pressure. 28 kg/cm^2)*

Table 2. Nutritional analysis and digestibility of exploded Mosochiku

Samples (Mosochiku)	Steaming time (min)	DM (%)	OM	CW	ocw	Ash	DM (%)	OM (%)	ocw (%)
			Nutritional analysis % of DM				in vitro Digestibility		
Unexploded	0	92.4	98.0	94.1	93.2	2.0	9.6	8.0	3.2
	1	93.3	98.0	73.0	72.4	2.0	32.6	31.8	7.1
	2	94.5	98.8	72.3	71.6	1.2	33.8	33.5	8.1
Exploded	4	91.8	99.0	71.1	70.3	1.0	47.8	47.3	25.8
	8	91.9	98.9	81.0	80.1	1.1	48.6	48.7	36.6
	16	91.2	98.9	82.3	81.5	1.1	50.0	49.8	39.1

Table 3. Nutritional analysis and in vitro digestibility of exploded materials

	DM (%)	OM	Crude protein	Crude fat	OCW	DM (%)	OM (%)	ocw (%)
	Nutritional analysis (%) of DM					in vitro Digestibility		
Mixed hey of orchardgrass and timothy	85.8	90.9	18.1	2.0	61.9	70.2	68.5	53.7
Alfalfa	86.5	89.9	20.1	2.4	46.4	64.0	64.4	31.1
Rice straw (unexploded)	86.1	85.1	5.2	1.8	60.9	43.6	43.7	20.9
Rice straw (exploded) (24 kg/cm^2, 4 min)	90.2	84.6	4.5	2.2	56.8	69.1	75.0	64.2
Bagasse (unexploded)	92.0	97.2	–	–	93.7	41.6	41.8	39.6
Bagasse (exploded) (27 kg/cm^2, 2 min)	91.9	96.9	–	–	77.5	63.3	65.8	57.2
Japanese larch (unexploded)	90.3	99.8	–	–	88.4	11.6	12.1	0.6
Japanese larch (exploded) (28 kg/cm^2, 4 min)	92.3	99.7	–	–	72.1	29.1	29.4	2.4
White birch (unexploded)	94.9	93.7	–	–	83.5	13.3	13.4	2.8
White birch (exploded) (28 kg/cm^2. 4 min)	87.4	86.8	–	–	51.4	76.5	76.5	60.6
White birch (exploded) (26 kg/cm^2, 4 min)	25.2	99.8	0.6	3.4	75.8	52.7	54.0	41.0
EXW with P. valioti (26 kg/cm^2, 4 min, 4O°C. 14 days)	40.7	97.2	7.2	0.9	82.7	52.4	52.7	45.4

to easily digestible materials in a mixture of the stomach juice of a sheep and artificial saliva of McDougall. Exploded Mosochiku and rice straw gave 50% and 75% digestibility of organic matter (OM) in comparison with 8.0% and 44% of those in the unexploded samples, and 39% and 64% digestibility of organic cell wall (OCW) (unexpioded samples, 3.2% and 21%). respectively. Thus, digestibility of Mosochiku EXB and white birch EXW is comparable to that of standard feeds, orchard-timothy (68.5%) and alfalfa (64.4%) (Table 2 and 3).

Digestibility of white birch EXW by cattle and goats in a preliminary investigation also showed a better value (90%) than that of hey cube (73%). Body weight of the goats fed with white birch EXW were the same to those of control (Kameoka et al., unpublished data). In addition, we recently found (Tanahashi et al., in press) that the culture of Paecilomyces varioti which was developed by Forss et al. (1976) to produce microbial protein, with white birch EXW considerably improved nutritional quality of EXW (crude protein content increased to 7.2%. Table 3) as ruminant feed. Sugars derived from hemicelluloses, phenolic compounds from lignin, and 5-hydroxymethylfurfural in water soluble fraction of the white birch EXW were almost completely catabolized by the culture. It is thus concluded that EXB and EXW are suitable for fermentation and ruminant feed. It was also shown that the steam-explosion process is one of the best pretreatment of bamboo and woody residues for enzymic saccharification, and preparation of ruminant feed and wood chemicals.

Acknowledgement

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The use of Bamboo as Waterpipes

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Abstract

Tanzania is one of the poorest countries in the Third World. About 10 years ago the Tanzanian gouernment, guided *by the National Political Party, the CCM, introduced a village settlement policy. Around the same time, the Ministry of Water, Energy and Minerals, started the Bamboo Project in support of the* village *settlement* policy and *to reduce dependency on imported materials as* well as *to* provide *water to the rural population by quickest and cheapest means. Most of the activities were centered on the use of bamboo as a piping material, The use of bamboo in the Tanzanian rural life is feasible and about 100,000 people are getting water through bamboo water systems. The whole construction activity is labour intensive carried out at village level with the exception of the design work. The Tanzanian government* has *adopted this technology as a viable alternative for rural water supply and a division has been formed within the Ministry of Water, Energy and Minerals.*

Introduction

The Bamboo Project has been active now for a decade in researching and promoting the use of bamboo as water pipes within Tanzania. We started investigations on the use of locally available materials as water conduits to reduce reliance on conventional materials. The usage of these materials should be undertaken with an eye on economisation and reduction of the foreign exchange component in construction works. Fields of application could be village water supply systems and small scale irrigation works. Although bamboos have been traditionally used as water conduits in many parts of the world, scientific information regarding its behaviour as a water pipe is very scant. Morgan (1974) reports the use of bamboo pipes in Ethiopia and the Indonesian engineer Sudjarwo constructed a six kilometer pipeline on the slopes of the Merapi Volcano, Java. In Tanzania the use of bamboo as water conduits was unknown, although van den Huevel (1981) reports on one village where bamboo was used as a water pipe. The project has so far constructed 150 km of bamboo pipe lines in 28 villages, supplying water to a 100,000 people who are benefitted. Though there was initial resistance from the Ministry of Water against this “backward’* technology, the project is gaining more recognition for its activities and since July, 1985, it has become a division within the Ministry. The project is regarded as a good example of the theory of “self-reliance” as expressed in the Ujamaa policy of Tanzania.

Types Of Bamboo

The first bamboo water supply scheme at the shores of lake Victoria was constructed of *Oxytenantera abyssinica* and *Bambusa vulgaris* (Clayton, 1979). In South of Tanzania vast forests of bamboo are found most of 1500 meter a.s.l. The indigenous bamboo is abundantly available here and is very suitable for water piping. *Arundinaria alpina,* or the green mountain bamboo grows gregariously but not in clumps (monopodial). The density is about 5,000 stems per hectare. Culms grow up to 18 mtr and show the internal diameters between 50 – 85 mm. Because the project does not practise clear cutting, the forest regenerates after 4 – 5 years. No specific records are available on flowering of *Arundinaria alpina* in Tanzania. (Wimbush, 1945); the other sympodial species used in the project is Bambusa vulgaris which was brought to Tanzania during the German colonial time (1890 – 1918). It is less straight than the green bamboo, and cutting it into right sizes is also more labourious. However these disadvantages are offset by its bigger diameters, up to 125 mm and its greater pressure bearing capacity. It is abundantly found north of lake Nyasa (Fig. 1), where it Is also used in housing construction. When all engineering and preservation problems are solved they can be used satisfactorily.

Measurement to determine variation in bore size along the bamboo stem of Arundinaria alpina. revealed that the portion of the bamboo starting from one meter above the ground up to five meters was of uniform bore size and thickness. For a 50 mm (internal diameter) bamboo pipe there was an average difference of 1 mm over the 4 mtr. while for a 75 mm pipe this difference was almost nil. Experiments carried out to ascertain pressures which bamboo can withstand revealed that the material-is capable of taking very high instantaneous pressures. For Arundinaria alpina values up to 6 bar were recorded and for Bambusa vulgaris it sometimes reached 10 bars. However the pressure withstanding capability differs very much from bamboo stem to stem and that maximum values drop considerably when the stem is exposed to those pressures for longer times. No parameters could be established which can correlate or predict the pressure withstanding capability. From experience gathered in the field. it was concluded that the working pressure for Arundinaria alpine should not exceed 1 bar and for Bambusa vulgaris 2 bars. When the bamboo is reinforced by putting wire aroud it. these values-can reach 2 – 3 bars. The low real working pressure for the bamboo pipe may be caused by the water hammer impact. The installation of water hammer absorbing devices may lead to enhanced working pressure ranges. From discharge – pressure measurements conducted at the Hydraulics section of the Department of Civil Engineering, University of Dar es Salaam. the variation of the friction factor (X) was determined by the Darcy Weisbach equation with Reynolds number (Re) (Fig. 2). The plotted Moody diagram clearly depicts the values plotted in the turbulent flow zone. Consequently the use of the exponential formula would be justified. The values of Manning's and Hazen-William's roughness coefficient were determined and found to vary between 0.013 – 0.016 n and 75 – 90°C respectively. The lower n-value indicating good node removal and the higher ones poor node removal.

Preservation

When burried in the ground as a pipe, unprotected bamboo will deteriorate rapidly and in the first village constructed it was observed that part of the pipes were destroyed within two months time by termites. It is not feasible to construct the pipe line Above ground. Cattle and people will damage it easily, while cracks develop rapidly when water flow stops. Because forest and village are in most cases widely seperated, replacements are not done easily.

The problem of termite attack was solved by the use of chlorinated insecticides and the chemicals are sprayed in the trench as solutions of 0.5% aldrin or 1% chlordane. Pipe and chemicals are kept at a distance by partly backfilling the trench before the bamboo pipe is laid. Possible contamination of the watek through these chemicals was investigated by the Tropical Pesticide Research Institute at Arusha. Tanzania, and the laboratory of the water chemistry group of the Delft University of Technology, the Netherlands. Results showed that no health hazards arise from the use of these pesticides. (van den Heuvel 1981). Their persistance in the environment makes them very useful for long-term protection and since 1977, no failures due to termite attack have been reported (Lipangile 1985). In November 1984 a case of termite attack was reported in the first village constructed, Likuyufusi. This continued occasionally this year, indicating that retention values of the pesticide in the soil are becoming less which is in accordance with reported data (Matsumura 1972). Depending on soil condition, temperature, pH and organic material a reapplication of the chemical will be necessary after 7 to 15 years. Rot becomes a severe problem in bamboo water pipes after 3 – 5 years. An early experiment with tar culms gave good results (up to 8 years and not for life), though this was temporarily abandoned. Another strategy adopted was the intermittent chlorination of bamboo water schemes. This killed spores of fungi as well. Since starting this practice there has been a remarkable improvement in performance for the existing schemes. More research should be done to determine the concentration and period of usage. Resuming, present preservation technique involves: a) spraying of the trench with chlorinated pesticides; b) coating the outside with tar and c) intermittent chlorination.

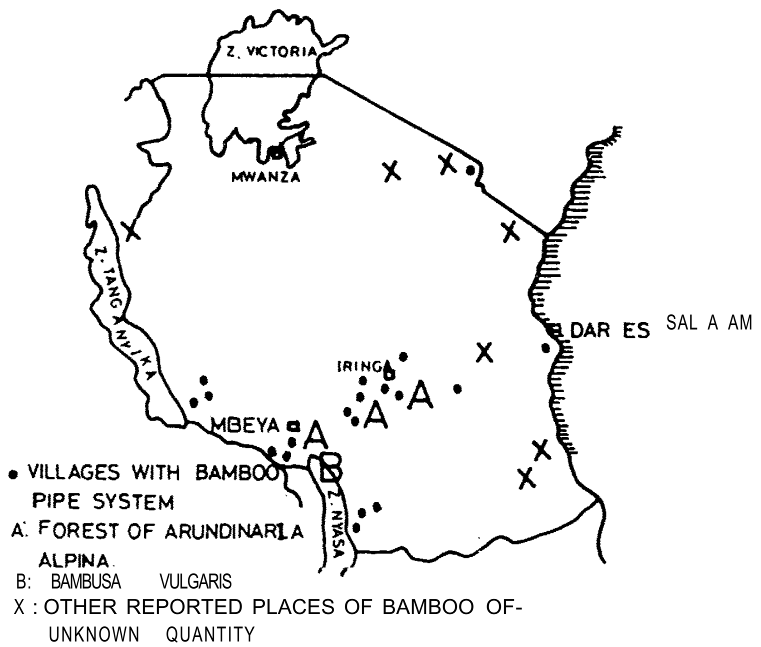
Extensive research has been carried out to impregnate the bamboo culm with other preservatives and all such tests failed because of the leaching of the preservative into the water. It is thought that enhanced durability should be possible by coating the pipe (inside and outside) with epoxy materials. When necessary a fungicide (copper sulphate) could be impregnated in the culm before applying the coating. It has been observed that durability of the bamboo pipe is increased by: a) clean water; b) careful design and construction aimed at a water saturated pipe; and c) construction of schemes at higher (= colder) altitudes. Taking these observations into account, present preservation techniques should protect the pipe for more than 10 years.

All the bamboo water schemes constructed so far are by gravity flow. The intake is normally a weir across a perennial stream. The design of the scheme is mostly based on a 24-hour flow demand from intake to storage tank and for the distribution system on a peak-flow demand. Breakpressure chambers are constructed where the head exceeds the pressure ratings of the bamboo pipes.

The pipe making and laying process involves the following:

- Mature stems of over 3 years age are cut in the forest. Presently the project uses only one forest near Mbeya (Fig. 1)
- 4 meter pieces are transported to a nearby river.
- the nodes are partly removed and the stems are submerged for at least three months in the river to allow desapping. If fresh bamboo are used, the water will get a horrible smell.

FIG. 1: MAP OF TANZANA



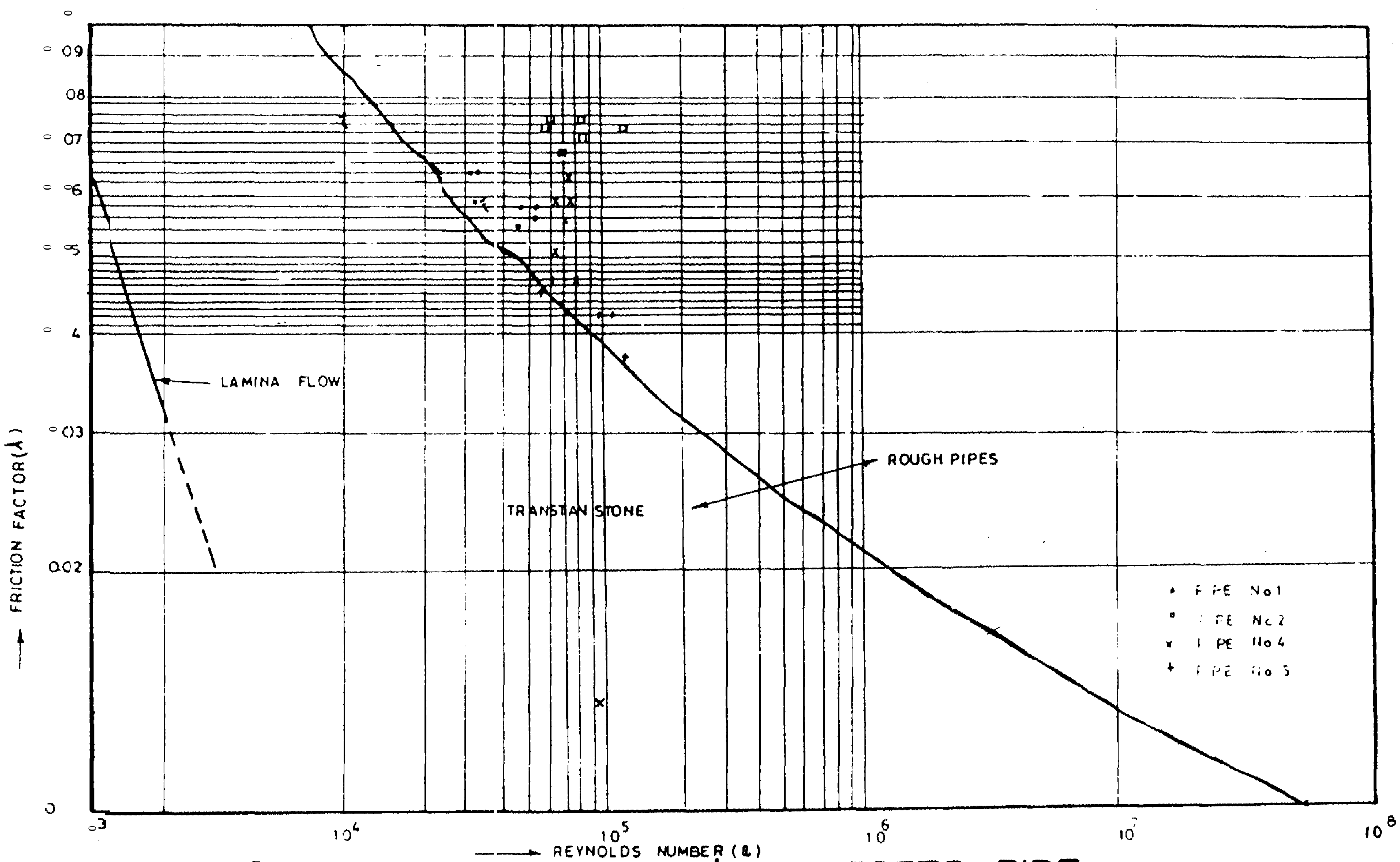


FIG 2 FRICTION FACTOR λ OF TESTED PIPE ON MOODY DIAGRAM

- from this centralized pond the bamboos are transported to the village construction sites.
- here again the bamboos are stored in a pre-constructed pond.
- the bamboo pipes are reinforced with galvanized wire.
- the butt-ends are sharpened by knife to fit the joint.
- nodes are manually removed by drilling with a 2.5 mtr. long steel rod on which augers of different sizes (to fit the different diameters of the bamboo) can be screwed.
- bamboos are air-dried before they are submerged in a boiling tar solution for 2-3 minutes. Coating is only applied on the outside.
- After drying the pipes are transported to the trenches.
- the trenches have been sprayed with a 0.5% solution of afdrin and are partly backfilled.
- the pipes are laid and jointed by pieces (20 cm) of polyethylene, class B (6 bar).
- Before inserting the bamboo pipes the joints are slightly heated to allow expansion. The pipes are hammered into the joints, which will form upon shrinkage a leak-proof joint.
- the trench is backfilled with some soil. On top of this again afdrin solution is sprayed.
- finally the whole trench is backfilled.

In this construction methodology all fittings, T's, connectors, reducing sockets, breakpressure chambers and domestic points used are of conventional materials.

Maintenance

During construction period two villagers are selected and trained in construction activities. After completion of the scheme they receive a supply of spare bamboos and other materials to enable them to carry out repair works. They are also supplied with a stock of chlorine lime. Each month they are obliged to send a maintenance report to the HQ at Iringa. In this report they should indicate the number of failures during previous month (1 failure = 1 pipe of 4 mtr has been replaced) and the cause of these failures. They also report depletion of stock. From these reports the average number of replacements received in a month / per scheme can be calculated.

Failures could be due to:

- the use of ungafvanized wires for reinforcement and rusted wire, the plugs used to fill the insect holes often become loose, especially during the first months.
- Excessive water pressure developed (Msimbe, 1984).

Very seldom termite attack is reported but, if the bamboos rot, then the whole operation has to be repeated.

Economics

A 63 mm bamboo pipe is about 4 times cheaper than a focally purchased plastic pipe of the same diameter (Lipangife 1984). The economics of bamboo pipes were estimated by an independent evaluation mission to the Bamboo Project, paid for by the Swedish International Development Agency (SIDA). They came to the conclusion that bamboo pipes are cost competitive both in terms of financial — and economical annualized costs (Broconsuft 1983). From these cost analyses it is apparent that transport contributes greatly to the total costs (up to 50%). This can be reduced considerably by using bamboos in the nearby forests and by exploiting more than one forest. The economic advantage of a bamboo pipe depends also on what size of pofythene pipe it is going to replace. Msimbe, (1985) reports that at low gradients increased flows will be conveyed more economically by bamboo pipes.

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CCA Impregnation of Bamboo–Leaching and Fixation Characteristics

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Abstract

Leaching tests *carried out on CCA (Copper. Chrome, Arsenic) impregnated* Arundinaria alpina *bamboo by Boucherie method, revealed that As was leaching excessively. An average of 15 % Cu, 17% Cr and 34 %* As *could be removed by submerging 2 cm bamboo rings in water. Concerning total salt retehtion, Boucherie impregnation was successful. An average of 12.0 kg* salt per *cubic meter of bamboo was retained. The leaching results were in marked contrast to earlier laboratory findings with CCA impregnation of bamboo sawdust. These experiments showed that good fixation is possible when sufficiently high (= 5 – 10 %)* concen*trations* of *CCA are used. Differences are explained by discrepancies between the pathways of fixation that are followed. Within the bamboo culm, fixation is mainly the result* of *the formation* of Cu – Cr – As complexes *in the vascular bundles. From these vascular bundles the* metal *ions diffuse slowly to the surrounding tissue. In sawdust, fixation takes plalce through the formation* of *CCA complexes with the bamboo constituents – cellu*lose and lignin-. *In* this process fixation of chromium *onto cellulose and lignin is the keystep.*

Introduction

Chromated Copper Arsenate (CCA) formulations have been in use as commercial wood preservatives for more than 45 years and these are the most effective wood preservatives, first developed by Kamesam in 1933. He conceived that copper sulphate, a proven fungicide, and arsenic pentoxide, a proven insecticide, in combination with potassium dichromate, a fixing agent, should contain the properties of an excellent wood preservative. Since the early development of Ascu, as the first copper-chrome-arsenic preservative was called, others have become available on a commercial scale. These included Tanalith C, Celcure A and Boliden K33. They differ in ratio of the used components. Copper is used in the form of copper oxide or copper sulphate. Chromium can be found as chromium trioxide, sodium chromate or potassium dichromate. Arsenic is used as arsenic pentoxide of different water of crystallization. The experiments described in this paper were carried out with Tanalith C. Its composition is given in the experimental part of this paper.

From the available data all of the CCA formulations appear to be excellent wood preservatives, especially for soft woods. In hard woods, early failures may occur. The wide spread use of these chemicals in wood protection was greatly encouraged by its adherence property to the wood. Arsenault (1975) reported the use of CCA treated timber in all kinds of structures where resistance to leaching and high fixation degrees were needed and proven i.e. cooling towers. water storage tanks, flumes, mushroom trays, tomato and grape stakes. Dunbar (1962) described the fixation of water-borne preservatives in cooling tower timber. Henshaw (1978) reported the fixation of copper, chrome and arsenic in softwoods and hardwoods. The leaching of copper, chrome and arsenic from CCA impregnated poles was reported (Evans, 1978). All of them are good fixatives with low leaching rates.

With this background information, the Bamboo Project in Tanzania was started to investigate the use of CCA as a preservative for bamboo water pipes. The aim of the project is to develop a technology which replaces imported hardware elements in village water supply works by materials made out of locally available wood and bamboo. Bamboo could be a viable piping material when its durability could be guaranteed for more than 10 years. The well-defined components of the CCA preservative, the known toxicity and tolerance standards, the fixation properties and its protective working against termites and rot could make it an excellent preservative for bamboo water pipes if indeed protection and fixation could be proven for this case. Unprotected bamboo water pipes buried in the soil will be destroyed rapidly by termites (van den Heuvel, 1981). By spraying the trench with chlorinated insecticides (aldrin or chlordane) this problem could be overcome. Since the project started using these insecticides in 1977, no damage due to termite attack has been recorded (Lipangile, 1985). However rot is not prevented in this bray. Service data records show that without any additional protection bamboo pipes must be replaced within one to five years. Present preservation technique involves spraying the trenches with chlorinated insecticides, coating the outside with tar and intermittent chlorination of the constructed schemes (Msimbe, 1985), while careful design and construction – aimed at 100% filled pipes – may add to the life-span of the pipe. CCA impregnation of the bamboo culm would enhance life-span, reduce costs and facilitate the manufacture of the bamboo pipes.

Very little data is available on the use of CCA as a preservative for bamboo. In a report of the United Nations (1972). recommendations were made for the protection of bamboo in use under different conditions. A few other publications mentioned the advisable solution strength of CCA for bamboo treatment. Wimbush (1945) gives2%, Bleyendaal (1978) 10% and Purushotham et al (1965) 8%. The last author also reported that a retention of 5 – 6 kg/m^3 is needed for a 10 – 15 year protection. No data was available on the leaching and fixation of CCA in bamboo: Van den Heuvel (1981) reported the first part of this research on CCA impregnation of bamboo water pipes. The aim of the research was to investigate if CCA could be safely applied in bamboo water pipes. CCA impregnation of bamboo sawdust was carried out and assessed for leaching and fixation characteristics. According to these laboratory findings, field trials were performed with CCA impregnation of bamboo culms by Boucherie method. Most chemical analyses were performed in the Delft laboratory, while field experiments were carried out in Tanzania.

Results and Discussion

Type of bamboo: When not otherwise mentioned, all experiments were conducted with the bamboo *Anmdinaria alpha,* also called the green African mountain bamboo. It is the species most abundantly available in Tanzania and because of its size (internal diameter 50 – 75 mm) and straightness, it is very suitable as a water pipe.

Type of CCA: All experiments described in this paper were carried out with Tanalith C. A CCA-type preservative had the following composition (as % w/w) :

45% potassium dichromate ($K_2Cr_2O_7$) – molar ratio Cr 2.2; 35% coppersulphate ($CuSO_4.5H_2O$) – molar ratio Cu 1; and 20% arsenic pentoxide ($As_2O_5.2H_2O$) – molar ratio As 1.1.

It resembles closely the CCA type C, defined according to the American Wood Preservers Association standard PS-74. This standard defines the molar ratio for CCA type C as Cr/Cu/As as 2.0/1.0/1.1.

Tanalith C was chosen because it is the CCA preservative most widely used in Tanzania.

Chemical analysis of copper, chromium and arsenic: Copper and chromium were determined according to standard procedures for the atomic adsorption technique. An air-acetylene flame was used. The Tanzanian laboratory used a Pye Unicam SP 9, the Delft laboratory the Varian Techtronic 1100. When the concentrations became very low or the matrix influences high, the flameless technique was used in the Delft laboratory. The instrument. a Perkin Elmer S300. Arsenic was determined in the Delft laboratory by the normal hydride generation technique. AsH_3 was atomized in a quartz tube with an air-acetylene flame and measured with the Varian Techtronic 1100. At the Government Chemist laboratory, Dar es Salaam. AsH_3 was led through a solution of silver diethyldithiocarbamate (SDDC) and the red coloured complex measured at 540 nm with a spectrophotometer.

Determination of Cu, Cr and As in bamboo tissue: The total amount of copper, chromium and arsenic in the CCA treated bamboo was determined through digestion. Pieces, varying from 3 – 6 grams, were dried at 105°C and accurately weighed. They were transferred into glass tubes (ø , 4.0 cm x 30 cm), 25 ml of concentrated nitric acid was added and the tubes were slowly heated in an aluminium heating block at 40° – 60°C. After a few hours, another 25 ml of conc HNO_3 was added and heating continued at 160°C The digestion was stopped when all the bamboo had dissolved and the evolution of nitrous fumes had stopped. The solution was transferred quantitatively to a measuring flask and water added to make up a final volume of 100 ml. Concentrations of copper, chromium and arsenic were measured with the techniques mentioned and expressed as grams per kg of bamboo tissue.

CCA fixation onto bamboo sawdust: The CCA reaction in wood is a fixation reaction involving the reduction of hexavalent chromium to trivalent chromium, followed by the formation of a complex mixture of insoluble salts. According to Dahlgren and Hartford (1972 II and III) the final equilibrium fixation products are ion-exchanged Cu to the wood, $CrAsO_4$, $Cu(OH)CuAsO_4$ and $Cr(OH)_3$, although highly basic chromic chromates, persist for a long time. Depending on the pH, the various Cr^{VI} anions exist in equilibrium with one another as follows:

$$Cr_2O_7^{2-} + H_2O \rightleftharpoons 2HCrO_4^- \rightleftharpoons 2CrO_4^{2-} + 2H^+ \quad \text{(eq. 1)}$$

The reduction of chromium than takes place according to the following reactions

$$Cr_2O_7^{2-} + 14H^+ + 6e \rightarrow 2Cr^{3+} + 7H_2O \quad \text{(eq.2)}$$

$$HCrO_4^- + 7H^+ + 3e \rightarrow Cr^{3+} + 4H_2O \quad \text{(eq.3)}$$

$$CrO_4^{2-} + 4H_2O + 3e \rightleftharpoons Cr(OH)_3 + 9OH^-$$

The last reaction only takes place under alkaline conditions and is of no interest for the CCA – wood/bamboo system. During the course of chromium reduction, the pH will increase due to the depletion of H^+ ions. pH increase in time was measured for the CCA – bamboo system. 8 grams of bamboo sawdust was mixed with 8 ml of CCA solution of different strength (2%, 5% and 10%). The samples were placed in the dark and the pH measured in time with a flat-membrane pH electrode, The results are given in fig. 1, The date clearly indicate that there is a sharp initial rise in pH (pH of a 5% CCA solution = ± 2). An instant change in proton activity of this magnitude cannot possibly be explained by

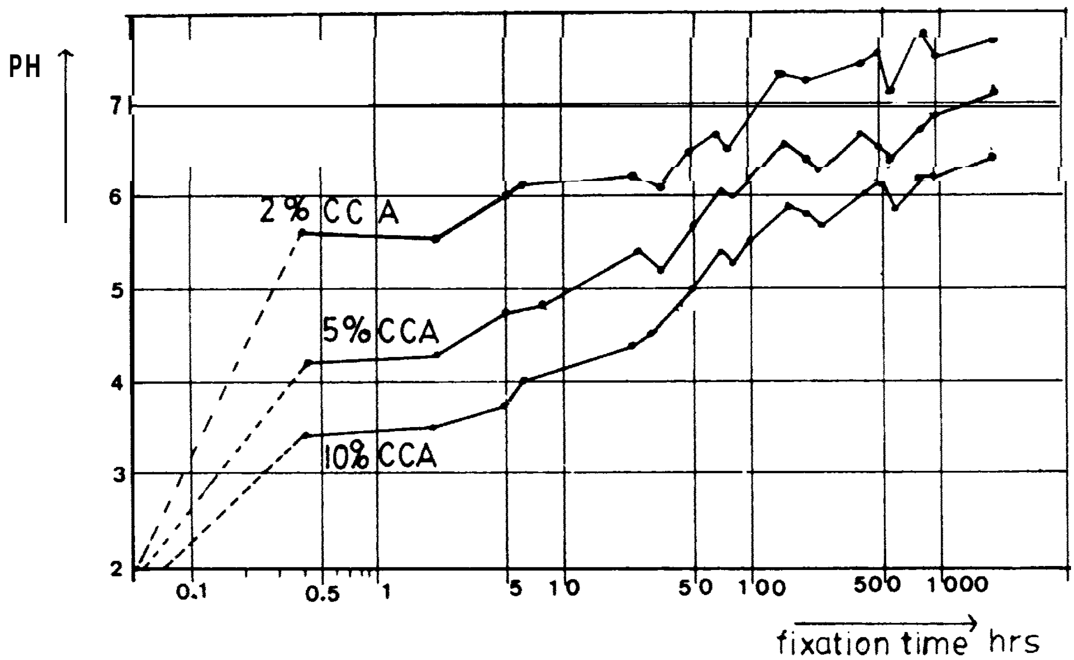


Fig. 1. The pH changes during fixation of CCA onto bamboo sawdust for different concentrations of CCA

chromic acid oxidation of bamboo tissue. Dahlgren and Hartford (1972 I) observed the same phenomenon for wood, although the effect was not so pronounced. The pH increased from 2.03 to 2.55 after 3 minutes for a 5% Tanalith C solution on pine wood. He attributed this to an absorption of chromic acid onto the wood constituents. However, in Tanalith C, the bulk of proton activity is generated through hydrolysis of arsenic. pentoxide, producing arsenic acid (H_3AsO_4), which will be partially ionized. Bamboo tissue must be capable of taking up H^+ ions (buffer capacity) resulting in the large instant pH increase, although it cannot be ruled out that rapid cdmplexing of chromium and arsenic anions contributes to the observed effect. The observed oscillating pH effects at the end of the fixation time can be attributed to conversion reactions of already precipitated materials into more stable compounds. Dahlgren and Hartford (1974 IV) postulated the conversion of primarily formed acidic copper arsenates into basic copper arsenates under release of arsenic acid, which in its turn reacts with the earlier formed chromic chromates. Pizzi (1981 I and 1982 IV) could not find copper arsenate complex in precipitates obtained after reaction of CCA type C with wood and its separate constituents – glucose/cellulose and guaiacol/lignosulphonate – and he postulated that the oscillating pH at the end of the fixation time was due to rearrangement of lignin complex under influence of the slow release of Cr^{III}.

For arsenic fixation, chromium reduction is essential. All the arsenic is precipitated as $CrAsO_4$ which can form complexes with lignin or stay loosely bound to cellulose (Pizzi, 1982 III). For chromium reduction, it is necessary to have: 1) sufficient H^+ ions – during chromium reduction H^+ is consumed causing the slow pH increase; 2) sufficient oxidizable material – chromium reduction is only possible when another compound is oxidized.

The formation of precipitates is favoured by: 3) a high final pH -- the higher the pH, the more insoluble the complex. Dahlgren (1975) gave a pH of 6, above which all salts were precipitated; 4) a low ionic strength – K_s (solubility product) is the product of activities. The higher the ionic strength, the lower the coefficient of these activities, the higher the concentrations.

To verify the above assumptions, bamboo sawdust was treated with different concentrations of CCA (2%, 5% and 10%) under addition of acetic acid (HAc) as a source of protons and sugar as an easily oxidizable material. The redox potential (E) and the pH were measured with flat-bottom electrodes during a two month period. Samples were kept in the dark. pH and E are plotted against each other in Figs. 2, 3 and 4 for the different solution strengths and the different additions.

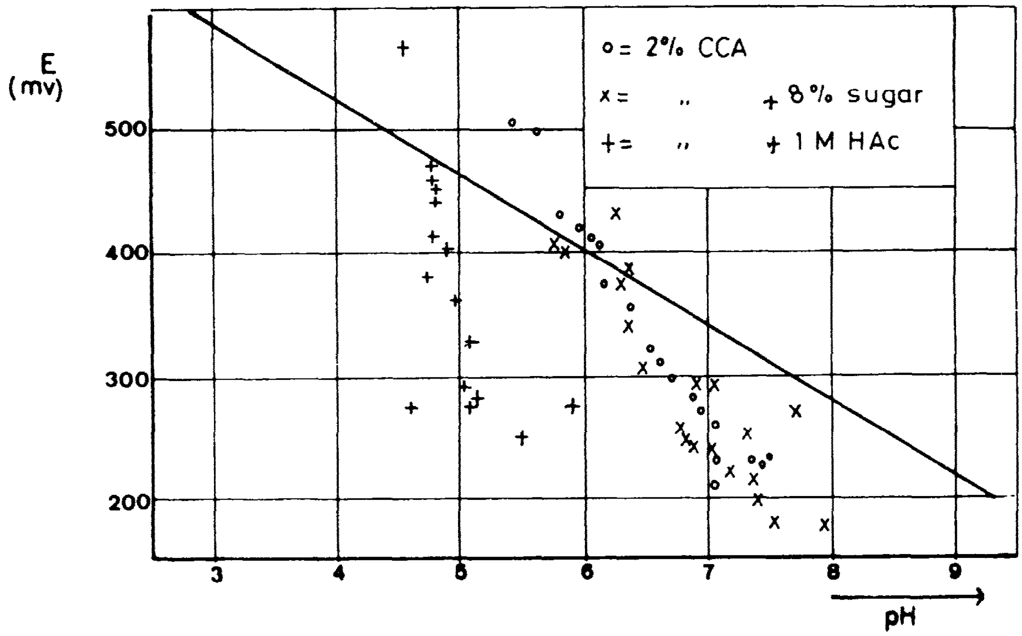


Fig. 2. E versus pH graph for the fixation reaction of 2% CCA (and different additions) onto fixation reaction. The straigth drawn line depicts how E changes with pH in a pure 2% CCA solution.

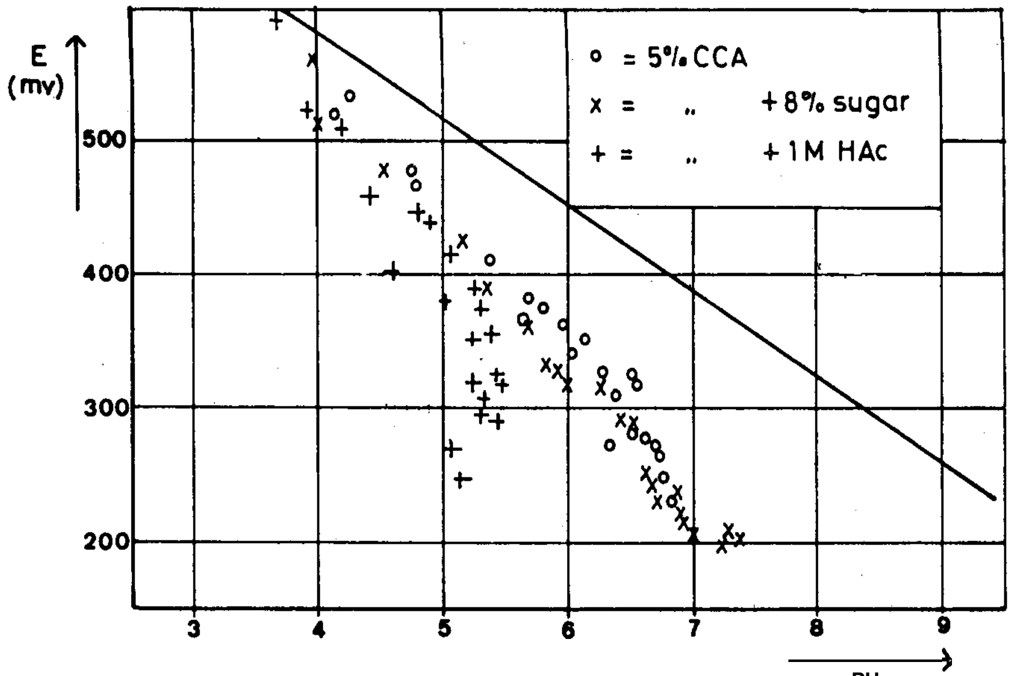


Fig. 3. E versus pH graph for the fixation reaction of 5% CCA (and different additions) onto bamboo sawdust. The straight line depicts how E changes with pH in a pure 5% CCA solution (for details, see text).

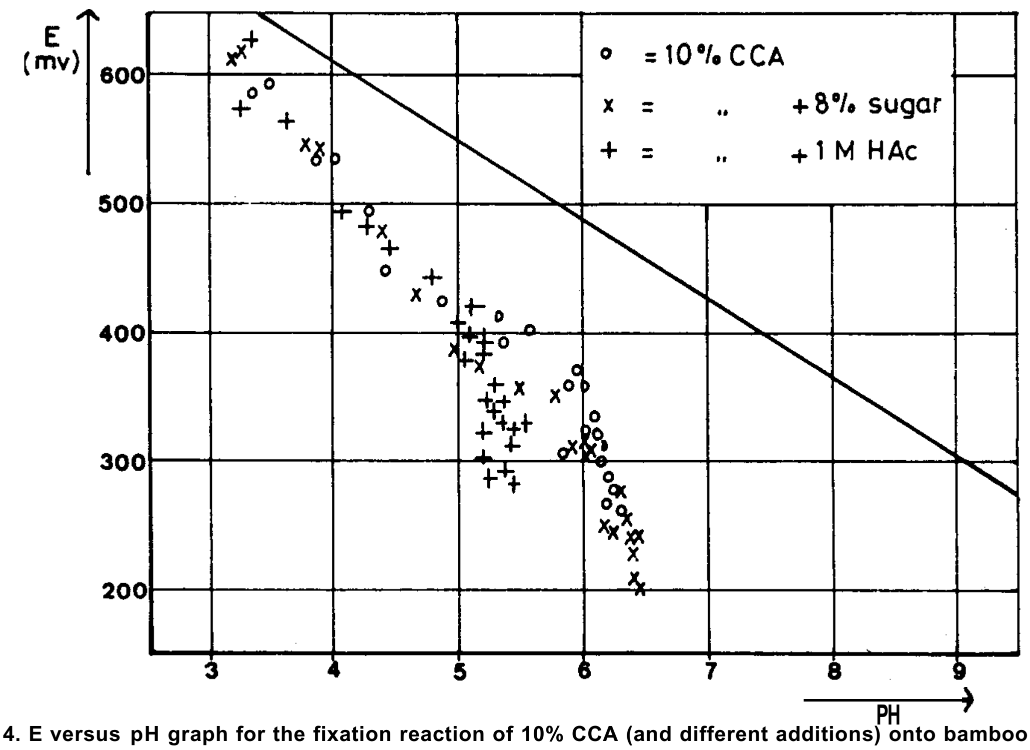


Fig. 4. E versus pH graph for the fixation reaction of 10% CCA (and different additions) onto bamboo sawdust, The straight line depicts how E changes with pH in a pure 10% CCA solution.

The straight lines in these figures depict how E changes with pH when no chromium reduction takes place. The further the point from this line, the more chrome VI has been reduced. After this fixation time the sawdust was washed twice with 100 ml deionized water to determine the amount of unfixed copper, chromium and arsenic and the concentrations in the washing liquid were measured. Table 1 gives the values of washed out copper, chromium and arsenic in mg per gram bamboo and as a percentage of total copper, chromium and arsenic retention. Table 1 also shows that with a low loading of CCA on bamboo, the fixation was very poor. A 2% Tanalith C solution gave a leaching of 13% for Cu, 30% for Cr and 29% for As. Dahlgren and Hartford (1975 V) reported the same phenomenon for Douglas fir. Ponderosa 'pine and to a lesser degree

Table 1. Leaching of copper (Cu), chromium (Cr) and arsenic (As) from CCA impregnated bamboo sawdust, using different concentrations of CCA and different additions for impregnation.

	2% CCA	+ 8% sugar	+ 0.2M HAc	+ 1.0M HAc	+ 4.0M HAc
copper	0.30 - 13%	0.37 - 16%	0.15 - 6%	0.63 - 27%	0.90 - 39%
chromium	1.22 - 30%	0.67 - 16%	0.32 - 8%	0.63 - 15%	0.99 - 24%
arsenic	0.87 - 29%	0.63 - 21%	0.51 - 17%	0.66 - 22%	0.95 - 32%
	5% CCA				
copper	0.16 - 3%	0.18 - 3%	0.18 - 3%	0.92 - 16%	2.18 - 37%
chromium	1.20 - 12%	0.26 - 3%	0.21 - 2%	1.61 - 16%	3.68 - 36%
arsehic	0.14 - 2%	0.16 - 2%	0.18 - 2%	0.79 - 11%	1.74 - 23%
	10% CCA				
copper	0.31 - 3%	0.24 - 2%	0.32 - 3%	0.98 - 8%	4.21 - 36%
chromium	2.06 - 10%	0.21 - 1%	0.94 - 5%	3.22 - 16%	10.51 - 51%
arsenic	0.24 - 2%	0.19 - 1%	0.23 - 2%	0.94 - 6%	3.02 - 20%

All values are expressed as mg metal leached per gram sawdust.
The percentages are of total retention of the metal ion.

Southern yellow pine when treated with 2 – 2.5% preservative solutions, although he mentioned unexpectedly high As leachability. Doubling the concentration also gave normal leaching rates. When we interpret the leachability of Cu, Cr and As for the different solution strengths with the results drawn in Figs. 2, 3, and 4, we can conclude that these high leaching figures for the 2% solution are due to poor chromium reduction. The figures also show that addition of sugar resulted in more chrome reduction at the end, although the reaction did not proceed any faster. The fixation of chromium was improved for all solution strengths when sugar was added (Table 1). Addition of acetic acid solutions gave 1 M and 4 M a larger chrome reduction (Fig. 5). However, because of the low final pH (pH ± 5) and the high ionic strength, precipitates *were* poorly formed, causing high leaching rates (Table 1). From Fig, 5, it can also be concluded that when H^+ is in excess. a

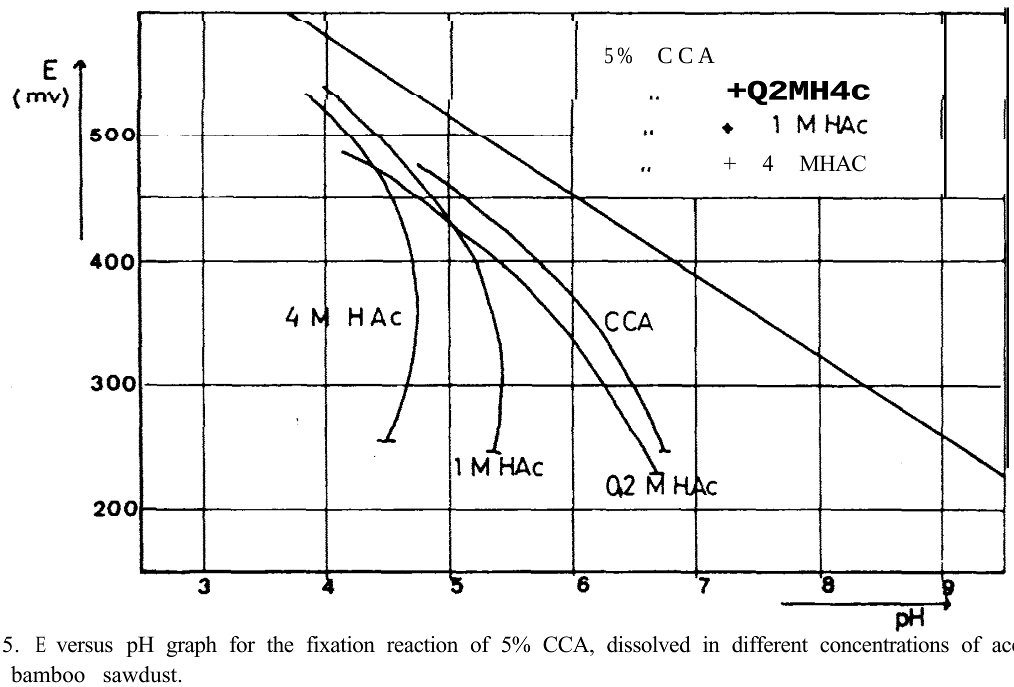


Fig. 5. E versus pH graph for the fixation reaction of 5% CCA, dissolved in different concentrations of acetic acid onto bamboo sawdust.

buffer of pH 4 – 5 will be formed (the natural pH of bamboo}. When we used a smaller quantity of HAc (0.2 M HAc), chrome reduction will be somewhat quicker, while the end pH hardly differs from that of the CCA solution without HAc. This indicates that the added protons were used. Chrome fixation is improved for all solution strengths.

From the prevailing data it is obvious that the availability of H^+ ions and oxidizable groups is not a hindrance for chrome reduction. When this should be the case, leachability of As for the 5% and 10% solutions should be the same or higher then for the 2% solution (the amount of bamboo was kept constant). Final pH and ionic strength do influence the sofubility of the complexes, but in normal reaction circumstances, ph is sufficiently high and ionic strength low, to guarantee low solubility .

With the model of fixation as postulated by Dahlgren and Hartford (1972 II and III) and Dahlgren (1975). it is difficult to explain the results obtained. The mere formation of precipitates as model of fixation appears very simple. Our date support the results of Pizzi. Pizzi (1981 I, 1982 II, III and IV) based his model on the reactions of hexavaient chromium with the different wood constituents. He concluded that this reaction takes place in three different reaction zones depending on PH.

First zone: Low initial pH, $Cr_2O_7^{2-}$

the dominant chromium anion

Cr^{VI} + cellulose kads$[Cr^{VI}$ – cellulose] complex

$Cr_2O_7^{2-}$ + lignin k_1 $[Cr_2O_7^{2-}$ – lignin] complex

Second zone: pH has increased, $HCrO_4^-$

the reacting chromium anion

Cr^{VI} + cellulose kads $[Cr^{VI}$ – cellulose] complex

$HCrO_4^-$ + iignin k_2 $[HCrO_4^-$ – iignin] complex

Third zone: further pH increase albeit slow, all

Cr^{VI} removed from solution

$[Cr^{VI}$ – cefiuiose] kred $[Cr^{III}$ – Cellulose]

Cr^{III} + cellulose

For the CrO_3/wood system, the reaction rates (k) were determined for the different zones (Pizzi 1981 I). For the first zone kads > k_1. This gives at the end of the first zone more Cr^{VI} complexed on cellulose. For the second zone $\ll k_2$. The reaction of the second zone hardly adds to the total amount of Cr^{VI} – cellulose complex. Reduction of chromium takes place through a rapid formation of Cr^{VI} – cellulose complexes in the first zone, followed by a "slow" *in situ* reduction on cellulose. The Cr^{III} – cellulose complex can release trivalent chromium into the solution where it forms complexes with arsenates. The second zone kads hardly contributes to the total amount of Cr^{III} formed. First and second zone reactions are rapid compared to the kred of the Cr^{VI} – cellulose complex. As was earlier mentioned, the pH of the CGA/bamboo system rises sharply at the beginning (Fig. 1). The effect is more pronounced for the 2% solution then for the 5% and 10%. Total chromium reduction depends on the length of time of the first zone. First zone reactions continue as long as the $Cr_2O_7^{2-}$ is the dominant chromium anion. Due to the sharp initial rise in pH for the CCA-bamboo system $Cr_2O_7^{2-}$ will be rapidly replaced by HCr04- (see eq. 1). Consequently only little Cr^{VI} will be complexed on cellulose and thus only little Cr^{III} will be available for chrome arsenate complexes, From Fig. 1 it can be concluded that the 2% solution forms the least Cr^{III} causing the high leaching rate of arsenic.

The effects of adding sugar and H^+ ions can also be explained by this model. Addition of sugar merely raises the initial concentration of the complexing cellulose/sugar. Because of this higher concentration, more Cr^{VI} will be complexed on cellulose/sugar and arsenic leaching will be reduced (sugar also reduces Cr^{VI}). Figs. 2, 3 and 4 show that in case of sugar addition, the reactions do not proceed faster but more Cr^{III} will be formed at the end. This is in accordance with the presented model. Addition of H^+ in the form of 0.2 M HAc gives for the 2% CCA solution a lower initial pH (Fig. 6). extending the period of the first zone reactions and therefore enhancing the total amount of chromium reduced. Arsenic leachability will be reduced (Table 1). Extensive washing of bamboo sawdust before CCA impregnation (sap removal) also gives lower leaching rates. Washed and unwashed bamboo sawdust was impregnated with 5% CCA solution. After four weeks arsenic leaching was determined. The washed bamboo gave very low leachability (1.1%). while for the unwashed bamboo, this figure

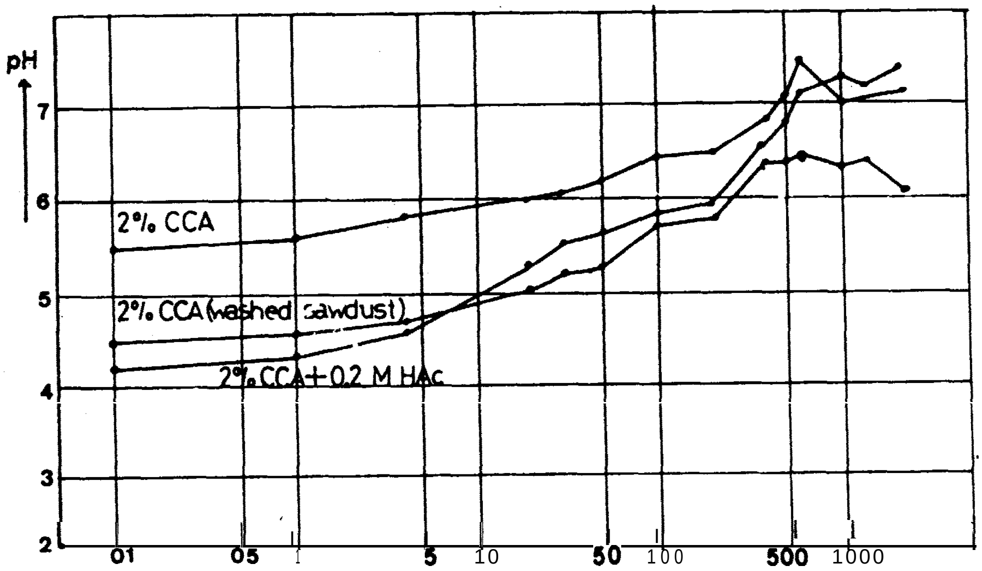


Fig. 6. The pH course during fixation of 2% CCA (with and without HAc) onto washed and unwashed bamboo sawdust.

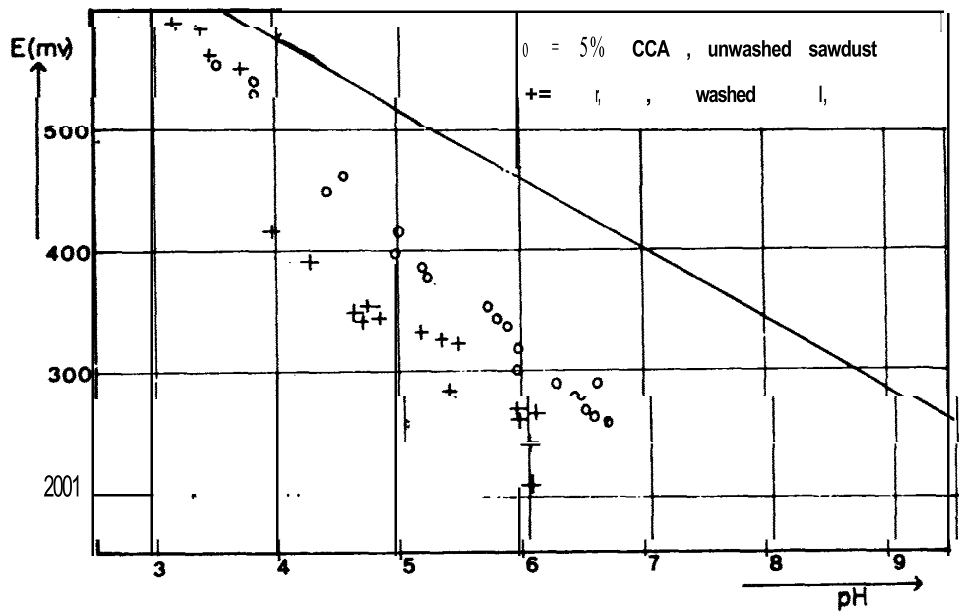


Fig. 7. E versus pH graph for the fixation reaction of 5% CCA onto washed (sap removed) and unwashed bamboo sawdust.

was 10% .-From Fig. 6, it can be seen that sap removal causes a lower initial pH. More chromium will be reduced according to the model presented earlier. This is verified by the E – pH diagram (Fig. 7). Washing may also result in a lower ionic strength, favouring the formation of precipitates.

The model presented does not offer an explanation for the behaviour of copper and chromium leachabilities. According to Piui, Cr^{VI} – lignin complexes are quite stable and not. easily leached out. Our data indicates that Cr^{III} is necessary to a certain extent for fixation of chromium into the bamboo (through the formation of chromic – chromate – lignin complexes). It is recalled that Pizzi obtained his results with guaiacof and lignosulphonate as model compounds for wood fignin. which is present in soft wood mainly as guaiacyl units and in hard woods as guaiacyl and syringil. The lignin of bamboo is a typical grass lignin of mixed dehydrogenation polymers of coniferyl-, singapyl- and p-coumaryl alchohois (Higuchi and Kawamura, '1966; Nakatsubo et al, 1972). Apparently the type of complexes and the rate of complex formation will be effected by this difference. Piui (1982 II) reports that 10 – 20% of the Cu is fixed onto lignin as $CuCrO_4$ complex and the remaining is ion-exchanged fixed to lignin and cellulose with a preference for lignin. No explanation can be offered for the observed lower leachability of copper in case of higher solution strengths and addition of H^+ ions. Sugar has no influence, probably indicating that Cr^{III} is not involved in copper complexing. A lower initial pH seems to favour Cu complexing onto bamboo.

From all the above, it can be concluded that the fixation mechanism of CCA onto bamboo resemhles closely the fixation mechanism of CCA onto wood, the main difference being the high initial rise of pH (due to the buffer capacity of bamboo). This causes for low solution strengths a poor chromium reduction and therefore high leaching rates of arsenic. Although the data presented in Table I gives the amount of easily removed (and thus not precipitated or complexed) copper, chromium and arsenic, severe leaching conditions will lead to additional removal of the different compounds. Tests carried out, representing severe leaching conditions (bamboo sawdust was put into a column and eluted with 10 1 of water), indicate that for a 2% CCA solution + 0.2 M HAc still **as** much as 24% copper, 11% chromium and 12% arsenic could be removed after washing. For the 5 and 10% CCA solution these figures respectively were 15% – 2% – 6% and 2% – 5% – 3%, again in favour of the high solution strengths.

CCA impregnation Of Bamboo Pipes by Boucherie Method

Liese (1980) and Tewari (1981) described the different methods to impregnate bamboo with water soluble chemicals. Van den Heuvel (1981) reported the experiments carried out by the Tanzanian Bamboo Project to impregnate CCA into the bamboo culm by different methods. He reported that methods using air-dried bamboos failed because of the high percentage of cracking. Steeping of fresh bamboos, hot and cold bath and sap displacement techniques were extensively tested. The steeping method gave satisfactory salt retentions (5 kg/m^3), but radial distribution was very poor. The inner part of the culm was poorly treated and the up-take through the inner wall was higher than from outside. However, the main disadvantage of the' steeping method was the crystallization of the salt on the inner- and outer culm wall, giving rise to health hazards during handling and usage, Steeping methods tested on bamboos with the partition walls intact were not successful because of the low retention of the CCA. Sap displacement techniques gave poor longitudinal distribution, although retention at. the butt-treatment end was sufficient. For further experiments, it was decided to use the modified sap displacement technique, namely the Boucherie method. Boucherie impregnation was carried out using gravity pressure. In the area where the Arundinaria alpha (green African mountain bamboo) grows, selection of a suitable site was easy. The supply vat was placed on top of the hill and connected through a 12.5 mm plastic hose with the distribution system at the foot of the hill. The gravity pressure applied was 20 m. For research purposes three separate systems were installed to run the different tests concurrently. Each of the systems had five connections for bamboo. Fig. 8 gives in schematic drawing the distribution system. The most difficult part of the Boucherie installation was the connection between the bamboo and the installation (the *'cap"). We used a piece of polyethylene, class B 0 63.5 mm, inserted in an ordinary poly connector. The cap operated well and was leak-proof when suitable (i.e., with the right diameter) bamboos were selected. As it was the aim to investigate retention, distribution and leaching, the installation was sophisticated enough. However for large scale operations, a cap should be developed which makes coupling and uncoupling easier and more rapid and which fits different diameters of bamboo. Boucherie impregnation was carried out with 5% Tanalith C solution. This solution was chosen following the results of bamboo sawdust impregnation. The use of a 10% solution led to rapid blocking of the vessels. .Bamboos, 4 m long, were treated, varying the treatment time. The normal procedure was overnight (O/N) treatment. Before leaching experiments were conducted, the bamboos were stored for more than three months in a shed. They were covered and kept wet.

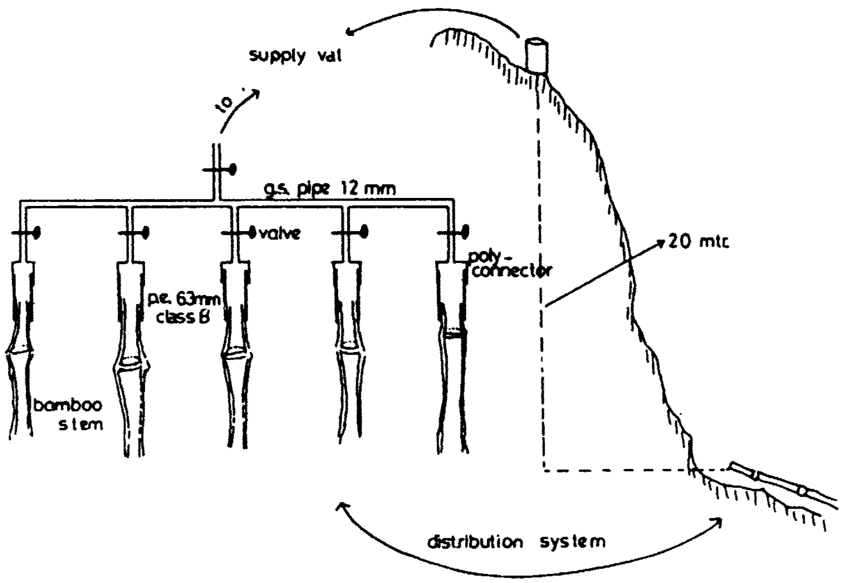


Fig. 8. Boucherie installation (gravity fed pressure).

Retention and distribution: Retention values (as kg salt/m^3 bamboo) were calculated from the -concentrations of copper, chromium and arsenic as found in the digestion experiments. When the first leaching experiments were performed, the amount of salt leached out was added. The tissue density of -the Arundinaria alpina was calculated to be 0.66 10" kg/m^3. The average retention for a 5% CCA solution was 12.0 kg/m^3. This was calculated from 23 bamboos, the standard deviation being 4.3. It is suggested that expressing retention values as kg salt/m^3 bamboo (as is the international practice in the wood preservation) is not very practical. Densities differ from stem to stem and species to species, while measurements of volume are laborious. It would be more convenient to use gr salt/kg bamboo. This gives an average retention value of 18.1 g CCA per kg bamboo (st.d. 6.6). Table 2 shows the average retention of copper, chromium and arsenic (g/kg bamboo) and their molar ratios within one stem. The last data clearly indicates that the salt composition has changed considerably during the Boucherie treatment. The amount of arsenic retained in the bamboo is lower compared to the original solution.

Table 2. Average retention of copper (Cu), chromium (Cr) and arsenic (As) for a number of bamboos and their respective molar ratios.

	Retention (gr/kg bamboo)			Molar Ra tio's		
Bamboo	Cu (st dev)	Cr (st dev)	As (st dev)	cu	Cr	As
1	1.05 40.20)	2.67 (0.89)	0.85 (0.20)	1.5	4.5	1.0
2	1.31 (0.43)	2.38 (0.65)	0.97 (0.18)	1.6	3.5	1.0
3	1.14 (0.50)	1.86 (0.65)	0.77 (0.16)	1.7	3.5	1.0
4	1.02 10.35)	4.51 (1.72)	0.92 (0.14)	1.3	7.1	1.0
5	0.93 (0.23)	2.13 (0.51)	0.95 (0.32)	1.2	3.3	1.0
6 A'	2.13 (1.15)	1.61 11.21)	0.88 (0.59)	2.9	2.7	1.0
B	1.92 (0.971	1.99 (0.62)	1.12 (0.18)	2.0	2.6	1.0
7 A	3.61 (2.30)	3.96 (1.64)	2.22 (0.511	1.9	2.6	1.0
B	2.81 (1.57)	2.82 (1.31)	1.50 (0.26)	2.2	2.7	1.0
8 A	1.15 (0.38)	2.39 (0.65)	1.85 (0.43)	0.7	1.9	1.0
B	3.04 (2.20)	2.36 (1.25)	1.39 (0.42)	2.5	2.4	1.0
			TANALITH C –	0.9	2.0	1.0

- A indicates that samples were taken 50 – 100 cm from butt-treatment-end.
  B samoles were taken 250 – 300 cm from butt-treatment-end.

For copper this is reversed (copper is best retained). From the large standard deviations of average retention of the different compounds within one stem (Table 2), it can be concluded that longitudinal distribution is very unequal throughout the culm. Fig. 9 depicts how retention increases with time for the different parts of the culm. It is seen that a certain length of time (the Minimum Treatment Time = MTT) is needed to guarantee sufficient retention throughout the culm. From the same figure it can be concluded that arsenic passes most rapidly (so fixes most poorly), while chromium fixes best. The uptake of copper continues for the longest period, indicating that copper diffuses best. The MTT depends on bamboo stem, species of bamboo, pressure applied and solution concentration. It is easily determined by measuring the specific gravity of the effluent preservative (which should closely resemble that of the original solution). Not surprisingly, it correlates well with the flow velocity of the preservative through the culm. It was observed that flow velocity decreases during treatment time. This was true not only in the case for CCA solutions but also when water was flushed through the stem. Initial flow velocity is strongly reduced in aged stems and will also drop considerably if the period between cutting and treatment is prolonged. We failed to impregnate bamboo by Boucherie method three days after cutting. For good treatment the time between cutting and impregnation should be as short as possible.

MTT longitudinal distribution will not be determined by distance to the butt-treatment end and longitudinal distribution is not equal. Large differences are observed (standard deviations in Table 2), but they do not correlate with the distance to the butt-treatment end. These differences are explained by the fact that complexes of precipitates are formed in the vessels (crystal growth). It is also clear from Fig. 9 that when the MTT is observed, longer treatment time would not enhance retentions. Radial distribution was investigated using rontgen-scanning techniques. Energy dispersive rontgen-spectra were made from different parts of the bamboo. Fig. 10 shows the spectra for a vascular bundle of untreated and treated bamboo and Fig. 11, for the parenchyma tissue for different energies. From these spectra it can be concluded that the bulk of the salt is retained in the vascular bundles and gradual diffusion to the surrounding tissues takes place (to detect the metals in the parenchyma tissue, higher energies had to be used). From these results it is obvious that the outer part of the culm is better protected due to the higher density of vascular bundles in this part. The results support the idea that retention and longitudinal distribution is mainly dependent

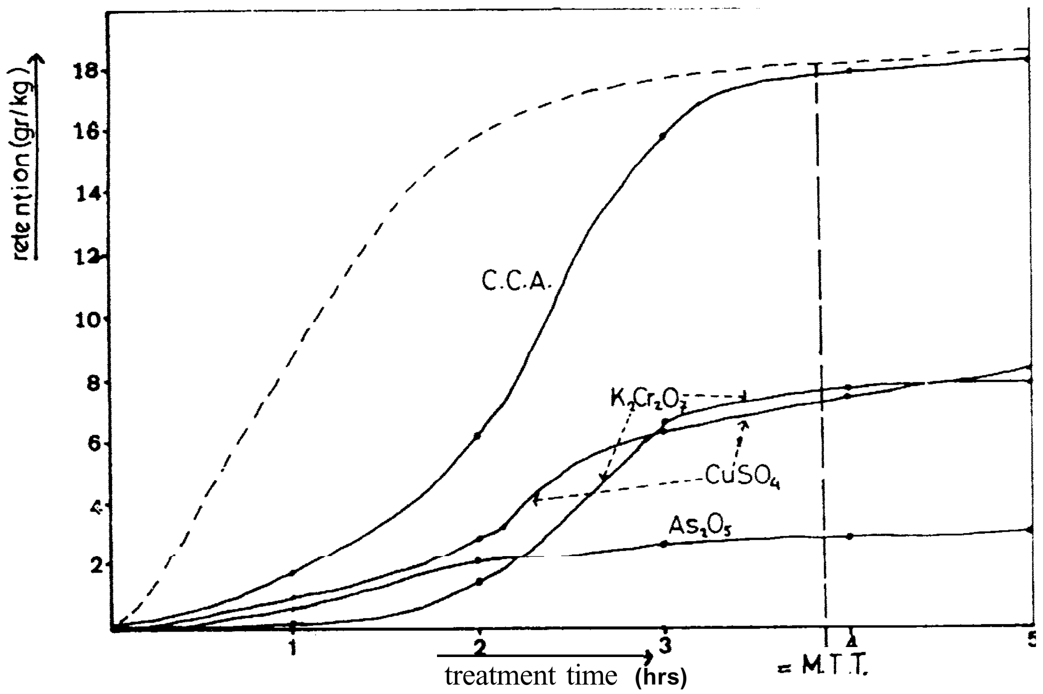
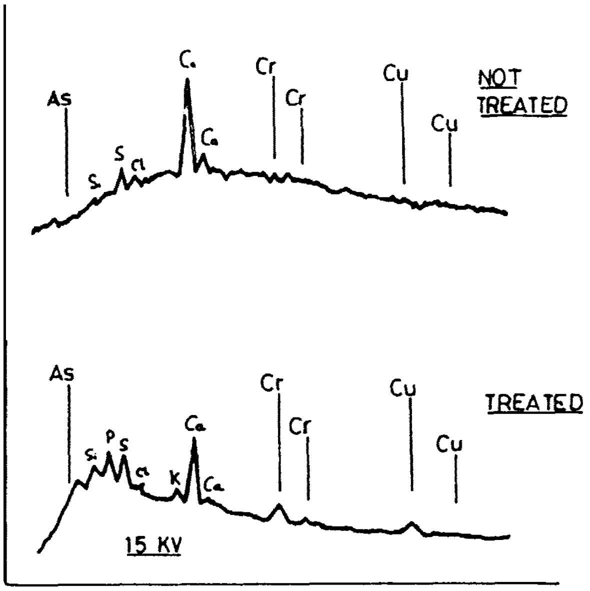


Fig. 9. Retention of $CCA/K_2Cr_2O_7/CuSO_4/As_2O_5$ as function of time determined at 3 m from the butt-treatment-end. The dotted line predicts how retention will increase near the butt-treatment-end.



Fig, 10, Rontgen spectrum of treated and untreated bamboo. The scan taken in a vascular bundle.

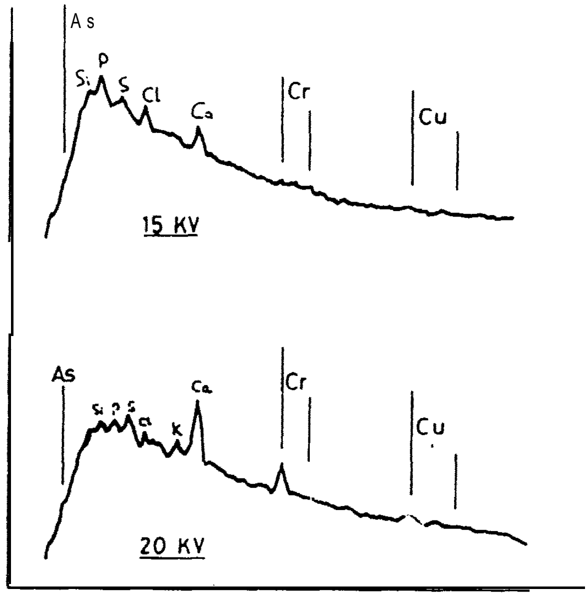


Fig. 11. Rontgen spectrum of parenchyma tissue of treated bamboo using different energies.

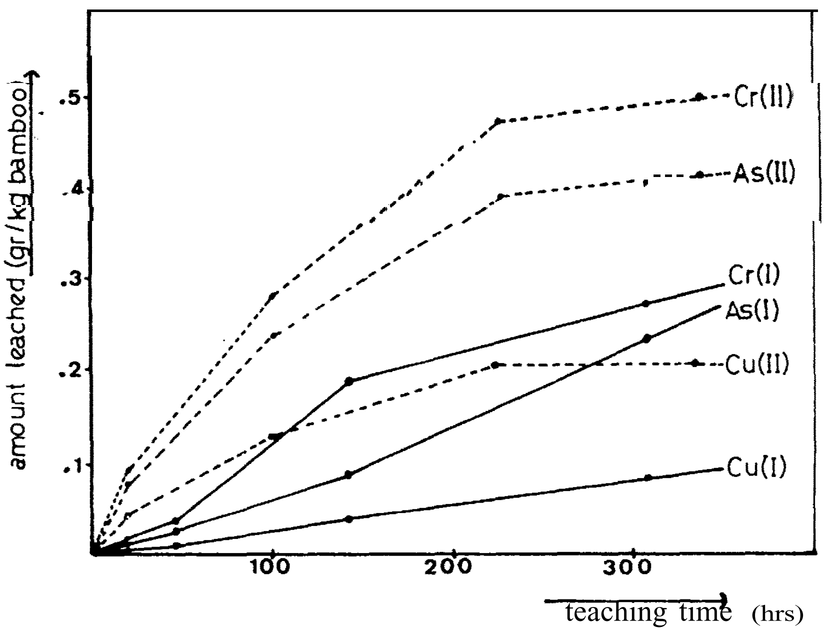


Fig. 12. Leaching of Cu, Cr and As from bamboo beakers (I) and 2 cm bamboo rings (II).

on formation of Cu – Cr – As complexes within the vascular bundles.

Leaching and fixation: To investigate leaching patterns. three kinds of experiments were conducted. In the first, pieces of CCA treated bamboo were placed in a glass column (ø 10 cm x 50 cm). The sawn ends were sealed with a silicone kit. The column was filled with water and this water in time analysed for copper, chromium and arsenic. In the second experiment rings of 2 cm were placed in water. This time the ends were not sealed. The third experimental set-up simulated most closely the use of bamboo as water pipe. Water was circulated with a pump (so under pressure) through the bamboo. From total water volume, content of the bamboo pipe and discharge, it could be calculated how many meters of pipe line correspond with one hour of pumped circulation. Figs. 12 and 13 show the characteristic leaching patterns for the different experiments. Leach-

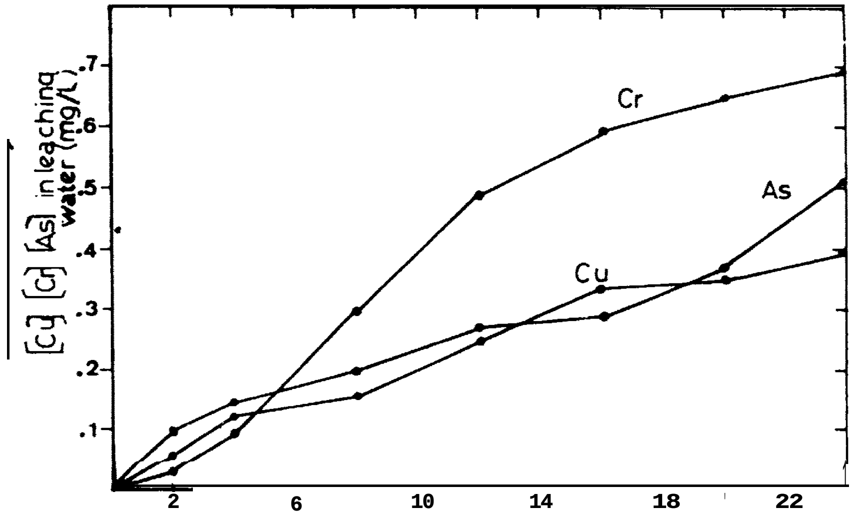


Fig. 13. Leaching of Cu, Cr and As from bamboo pipes through pumped water circulation.

ing is most severe in experiment II, due to the high surface/tissue ratio deliberately caused by not sealing the ends. After 20 days of submerging in water, leaching seems to have terminated for these experiments. Percentages of totally leached copper, chromium and arsenic were determined from these experiments II. For copper. the values ranged from 5 – 28%. average 15%. for chromium from 4 – 36%. average 17%. for arsenic from 7 – 68%. average 34% (Table 3). From Fig. 12, it appears that the leaching of CCA proceeds at an almost constant rate. This may be explained by assuming that leaching is a first order process, which is only dependent on the concentration of CCA in the bamboo; r = k CCA, r being the leaching rate and k the first order rate constant. Because CCA is present in large excess, the CCA concentration may be regarded as constant during the leaching experiment I. This gives a pseudo zero-order process. The leaching rate (r). mg/kg hr, and the first order leaching rate constant k = r/CCAtot (hr-‘) were calculated for Cu, Cr and As from the experiment I. Results are given in Table 4. Copper, chromium and arsenic leaching for the different pipes can be best compared by looking at the first order leaching rate constants, because in k differ-

Table 3. Retention (as gr metal ion per kg bamboo) and Leaching (% of retention) of copper (Cu), chromium (Cr) and arsenic (As) from 2 cm bamboo rings.

Bamboo	Copper		Chromium		Arsenic	
ring *	ret.	leac.	ret.	leac.	ret.	leac.
1	0.89	23%	2.04	24%	0.70	46%
2	1.35	14%	2.60	19%	0.97	41%
3	1.20	13%	1.95	15%	0.77	41%
4	1.09	24%	3.67	20%	0.92	24%
5	0.92	28%	2.32	30%	0.95	55%
6 A	3.12	5%	2.46	21%	1.21	42%
B	2.37	13%	2.51	11%	1.30	30%
7 A	5.84	9%	5.55	18%	2.66	33%
B	4.32	10%	4.05	22%	1.72	43%
8A	1.06	12%	2.82	4 %	2.05	11%
B	4.20	14%	3.47	5 %	1.81	14%

* = A indicates that samples were taken 50 100 cm from butt-treatment-end
B 250 – 300 cm from butt-treatment-end.

Table 4. Leaching rates (r = mg metal ion per kg bamboo per hour) and first order leaching rate constants (k = 10^{-4} hr^{-1}) for copper (Cu), chromium (Cr) and arsenic (As) in a number of bamboos,

Bamboo	Copper		Chromium		Arsenic	
	r	k	r	k	r	k
1	0.30	2.5	0.78	2.5	0.25	2.5
2						
3	0.28' 0.11	2.3 1.2	0.90 0.41	4.2 2.1	0.67 0.34	6.8 4.3
4	0.21	2.1	0.73	1.7	0.17	2.0
5	0.47	4.9	0.95	4.8	0.58	6.2
6 A'	0.28	2.5	0.61	7.8	0.84	15.1
B	0.14	1.0	0.27	1.8	0.42	4.5
7 A	0.36	2.6	0.83	3.5	1.10	6.1
B	0.71	5.4	1.60	10.0	1.70	13.2
8 A	0.06	0.5	0.20	1.0	0.26	1.6
B	0.18	1.0	0.31	2.5	0.45	4.6
average	0.28	2.4	0.69	3.8	0.62	6.1

• A= 50 – 100 cm fmm the butt-treatment-end.
B = 250 – 300 cm from the butt-treatment-end.

ences in loading of CCA are levelled out. From the data it is clear that copper leached less and arsenic most as a percentage of total retention. However because of the higher r values, chromium will contaminate the water more. There is a positive correlation between chromium and arsenic leaching.

All experiments show that when these pipes are used for transportation of drinking water. high concentrations of Cu. Cr and As can be expected in the water. A 2 m long CCA treated bamboo pipe was washed in the river for one month. After this washing time it was connected to the circulation installation (experiment III) and water was pumped through it for ten hours representing 500 m of pipeline. The next concentrations of Cu, Cr and As were measured:

500 m bamboo pipe	Cu	= 0.2 mg/l
	Cr	= 0.2 mg/l
	As	= 0.3 mg/l
Tanzanian standard	Cu	= 3 mg/l
allowed in	Cr	= 0.05 mg/l
drinking water	As	= 0.05 mg/l

These results do not need further elaboration.

Although the experiment II shows that leaching may terminate in time, extensive washing procedures on a large scale are not recommended because of high environmental pollution. It should even be questioned if the salt retained after extensive washing is sufficient for protection. The amount of salt retained was determined in a pipe installed as test pipe three years ago, and found to be down to 3.4 kg. Leaching and fixation were investigated for different procedures of Boucherie impregnation (first flushing with water – sap removal – or acid, following the results of bamboo sawdust impregnation). However, possible effects were masked by the very irregular leaching patterns of normally 5% CCA treated bamboo.

In the Bamboo Project, the results obtained with CCA – Boucherie impregnation of bamboo pipes were disappointing, High leaching rates of the toxic compounds make the use of a CCA – Boucherie treated bamboo pipe as water conduit impossible. This result is in marked contrast to the results obtained with CCA bamboo sawdust impregnation. For this system, good fixation could be reached when sufficiently high concentrations were used. Selective adsorption and diffusion of the different metal ions during and after the Boucherie process and invalidates the model as presented for the CCA – bamboo sawdust system. Experiments for CCA – bamboo sawdust impregnation revealed that a high instantaneous loading of CCA is necessary for good fixation (more than 50 g CCA per kg bamboo). This condition will be realized in the vessels, when we look to the amount of CCA in direct contact with the bamboo tissue. This is confirmed by the measurement of the pH of the effluent preservative. Immediately after starting the treatment, the pH of the collected sap reached 5.16 (the natural pH of the Arundinaria alpina bamboo). During the course of the treatment, the pH dropped to + 3.5. However, the CCA in the vascular bundles was hardly exposed to the reactive groups of the bamboo tissue and this low pH would not result in good chromium reduction (as in the sawdust system). Fixation of CCA is merely the result of the formation of precipitates within the sap vessels and even for this the situation is not optimal (low pH). Investigations of CCA – Boucherie treated bamboo pipes buried for three years in the soil as test pipes revealed that the bamboo was still sound, although slight nibbles of termite attack could be seen on the outside. The control pipes were totally destroyed by termites and rot. The total salt retained had dropped considerably due to the severe leaching' conditions. All experiments indicate that CCA – Boucherie treated bamboo will be well protected against termite attack and rot for a long time when not exposed to severe leaching conditions. By using different techniques of impregnation, it is possible that sufficiently high fixation can be reached. All techniques depend on diffusion of the' metal ions and therefore resemble closely the Boucherie impregnation. Experiments carried out with pressure impregnation gave an average leaching of arsenic of 44%.

Acknowledgements

The results presented here are the data of a joint-research programme of the Bamboo Project in Tanzania and the water chemistry group of the Delft University of Technology. the Netherlands. The research was financed by the Netherland Ministry for Development Cooperation (hard currency component) and the Tanzanian Ministry of Water (under which the Bamboo Project falls). The bulk of the chemical analyses were performed at the Delft laboratory by J. Donker. Mr de Leer (initially P. Schreur) supervised this work in his function as head of department. Mr Slob (a chemist) was employed through SNV (Netherland organization for Development Assistance) as a scientific coordinator of the research program in Tanzania. He was assisted by Mr Nangawe, a Tanzanian forest officer with a long standing experience in wood preservation. They conducted the field experiments, while laboratory facilities were put at their disposal by Dr Madati, Head of the Government Chemist Laboratory, Dar es Salaam. Here Mr Siafu assisted in the chemical analyses.

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Bamboo Plywood – A New Product of Structural Material with High Strength Properties

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Abstract

The paper describes the procedures involued in making bamboo plywood. It then discusses the comparative merit of the *product.*

Bamboo plywood is a panel consisting of an assembly of plies of bamboo sheets bonded together with the direction of the grain, in alternate plies at right angles. An adhesive of phenolic resin is used. The bamboo species used for the raw material is Phyllostachys pubescens (Mazd) which averages 9 cm in diameter at the breast height.

The processing procedure is as follows:

Bamboo culm is first crosscut into four or so with the desired lengths and the inner and outer surface layers are scraped out on equipment specially designed. The cuts are then split open into two or three pieces. Following a pretreatment by soaking the pieces in a cooking vat for several hours, the pieces are dipped in a vessel with a medium at a temperature far beyond 100°C so as to enhance the temperature of the pieces to a certain degree to soften the wood. This serves to thermoplasticize the Iignin and hemicellulose more effectively. The treated pieces are then spread out, flattened, dried and stabilized through a heated press and a breathing drier, specially used for processing bamboo sheets. The pieces are planed smooth and edged straight on both sides. This prepares, the material – faces, backs and crossbands – for the manufacturing of bamboo plywood. The forthcoming procedures are just the same as the manufacture of plywood. Bamboo plywood is extremely high in bending strength – modulus of rupture (MOR); modulus of elasticity (MOE) and it probably ranks as the highest among all of the structural boards and even as good as the solid wood of high density commercial timbers. Bamboo coupled with wood is a material of heterogeneity and anisotropy. This property may be evaluated as a disadvantage on the one hand and an advantage on the-other. Some may place this property of bamboo at a disadvantage in competition with other products. In fact, many of the disadvantages, real or implied, as decay and insect attack, could be overcome by intelligent use of bamboo, based on a comprehensive knowledge of its characteristics.

It is known that bamboo is exceptionally anisotropic in nature and this character could be overcome by crossbanding to a certain extent as desired. The problem is in developing the resulting characteristics to a much higher degree as we do in oriented strand board (OSB) and also in oriented strand composite plywood (OSCP). Bamboo plywood serves this purpose. As the orientation of fibers in bamboo is nearly perfect along the grain, the bending strength of the product is remarkably superior to those of OSB and OSCP. It is also high in flexible rigidity. In comparison with other structural materials other than wood and wood products, they are mostly isotropic and there is no way to strengthen the bending strength and stiffness as expected.

A tentative comparison of strength properties of a few structural materials is shown in Table 1.

We understand that the nature of the cell wall substance and its distribution as a system of thin-walled tubes makes wood very efficient in flexible rigidity. So does bamboo. This high flexible rigidity is most effective in members as beams in which length is far in excess of depth. In comparison with other structural materials, the weight – strength ratio for bamboo product is very favorable for some applications. This high stiffness – to – weight ratio exhibits a characteristic which is considered to be an important criterion for evaluating the mechanical properties of a

Table 1. Comparison of five wood based materials.

Material	Strength MOR (Kg/cm^2)	Properties MOE (Kg/cm^2)
Particleboard (random)	235	34,483
OSCP	740	42,200
Bamboo Plywood	1,175	211,000
Oak, Chinese species	1,506	149,000
Oak, American species	1,655	163,448

material and this form of cellular organization is also a highly efficient means for obtaining the maximum moment of inertia from a minimum amount of material. The moment of inertia of a bending member is vastly increased if a given amount of material is arranged as a tubular structure rather than a solid rod. For this reason, bamboo products have a high index of rigidity in comparison with solid structural materials and is well suited for use in situations that require elastic stability. Compared with wood, bamboo product is at least nine times as good an energy-absorbing medium as steel. This makes it an excellent material for floors and similar applications where energy absorption is important.

Bamboo, being similar to wood, is a cellular substance and in the dry state the cell cavities are filled with air, which is one of the poorest conductors known. Because of this fibrous structure and the entrapped air, bamboo has an excellent insulating property. The common building materials used in house construction with the exception of wood are not good insulators. In comparison with wood, the heat loss through common brick is six times and through a glass window eight times as great, whereas concrete and steel are fifteen and three hundred ninety times as conductive as wood respectively. Experiments show that the coefficient of heat conductivity of bamboo product is a little higher than that of wood, but the difference is too small to be taken into account.

Bamboo plywood associated with wood and wood products provides thermal insulation the year round. It is effective not only in winter against cold, but also in the summer against heat. Combined with wood, it is a remarkable structural material for shelter where an effective thermal insulating property is necessary.

Wood structures can withstand an impact load twice as great as that of static loading. It is also true for bamboo products. This exceptional impact strength gives it a considerable mechanical and economic advantage for structures designed to resist earthquakes or for situations where abrupt loads are imposed. Bamboo is susceptible to fungi and insect. Experiments demonstrate that no damage of decay and insect attack has occurred, when phenolic resin is used as the binder of the bamboo plywood. This is also the case in fire resistance. There is no reason why, if properly used, bamboo products should not last indefinitely. Because of the shortage and uneven distribution of forest resources in China, the supply of timber is far below the ever-increasing demands of the country. Therefore China's scientists explore all possibilities to use wood efficiently and develop new product replacement for it. The manufacture of bamboo plywood is perhaps one such achievement in this field.

China is lucky in having extensive bamboo resources with more than 300 species. There are 3,401,800 ha of bamboo stands of which 2,418,600 ha is made up of Phyllostachys pubescens. The growing stock is about 3,759,890,000 (3.796 thousand million) bamboo culms. On a hypothetical rotation of six years, the annual harvesting will be about 632,648,300 culms. An estimate on the number of culms of bamboo of 9 cm diameter needed for making 1 m^3 of bamboo plywood has been made on a pilot plant. The results show that 150 culms would be sufficient to meet the need at the present running level. This means a total of 4,217,650 m^3 of bamboo plywood which is equivalent to four times the present production of all the wood-based materials, could be made annually.

A Brief Introduction to the Bamboo Tower in Zurich, Switzerland

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Abstract

The details of a bamboo tower construction undertaken in Switzerland are described.

Introduction

Based on the sketch by Mr Peter Staub, a well-known plastic artist, a bamboo tower was set up as one of the exhibits in the "phenomena" Exhibition held in Zurich, Switzerland in 1984, and it really provided a rare opportunity in displaying the graceful bearing of a bamboo building. The tower was successfully completed through a joint effort by the Kunming Architectural Design Institute and the Kunming Construction Company. Facts proved that the sponsors of the Exhibition had actually made a wise decision with foresight and sagacity. The building added Iustre to the Exhibition and was widely acclaimed. It was later reconstructed in Rotterdam, Holland in the middle of 1985. With the maximum height of 22.50 m, it was divided into five floors, from bottom up each with 5.40, 4.05, 4.05, 6.0 and 3.0 meters high respectively. Furthermore, one large spiral slide with 19.50 m in height, 60 m in slope length and three small slides with 5.4 m in height were also provided. Since the building of this kind had hardly been seen, it attracted a good deal of attention and interest from the architectural circle and bamboo researchers.

General Considerations of Design

An equilateral triangle 2.40 m length for each side was taken as a basic plan unit. 49 honeycomb spaces were made up by means of a separation of floors, which had advantages of stable plain and fewer members in kind. In addition, the architectural appearance was very obvious. All these made the configuration of the building varied and colourful.

Details of Technical Treatment

The combined pillars were made up of 3-6 pieces of bamboo and bundled up at every meter by at least 10 strands of bamboo strings at each point. The lower end of the pillar was connected to its foundation through a steel plate. A timber was provided on the horizontal bamboo pole under the floor to form the combined upper chord of bamboo-wood which dispersed loads and reduced bending stresses as well as helped fix wood boards. The tongue and groove boards were arranged along the different directions to make the floor more even.

The following joints were used. i) the butt joint with wood/bamboo core plus bamboo pins, ii) the bake-bent joint, iii) the shear joint with a bracing piece, iv) the tenon joint with or without wood core, v) the screw joint with holding boards (used for central joint in three hinged arches), and vi) the joint with scooping-out plus bamboo pins. In the regular hexagon plain unit, spiral stairs were designed. The radial foot rest passed through the straight vertical pillars outside and central tubes were decorated with bamboo slips. Through ingenious arrangement of the bamboo poles, the entire stair hall was well revealed giving an appearance of the bamboo structure.

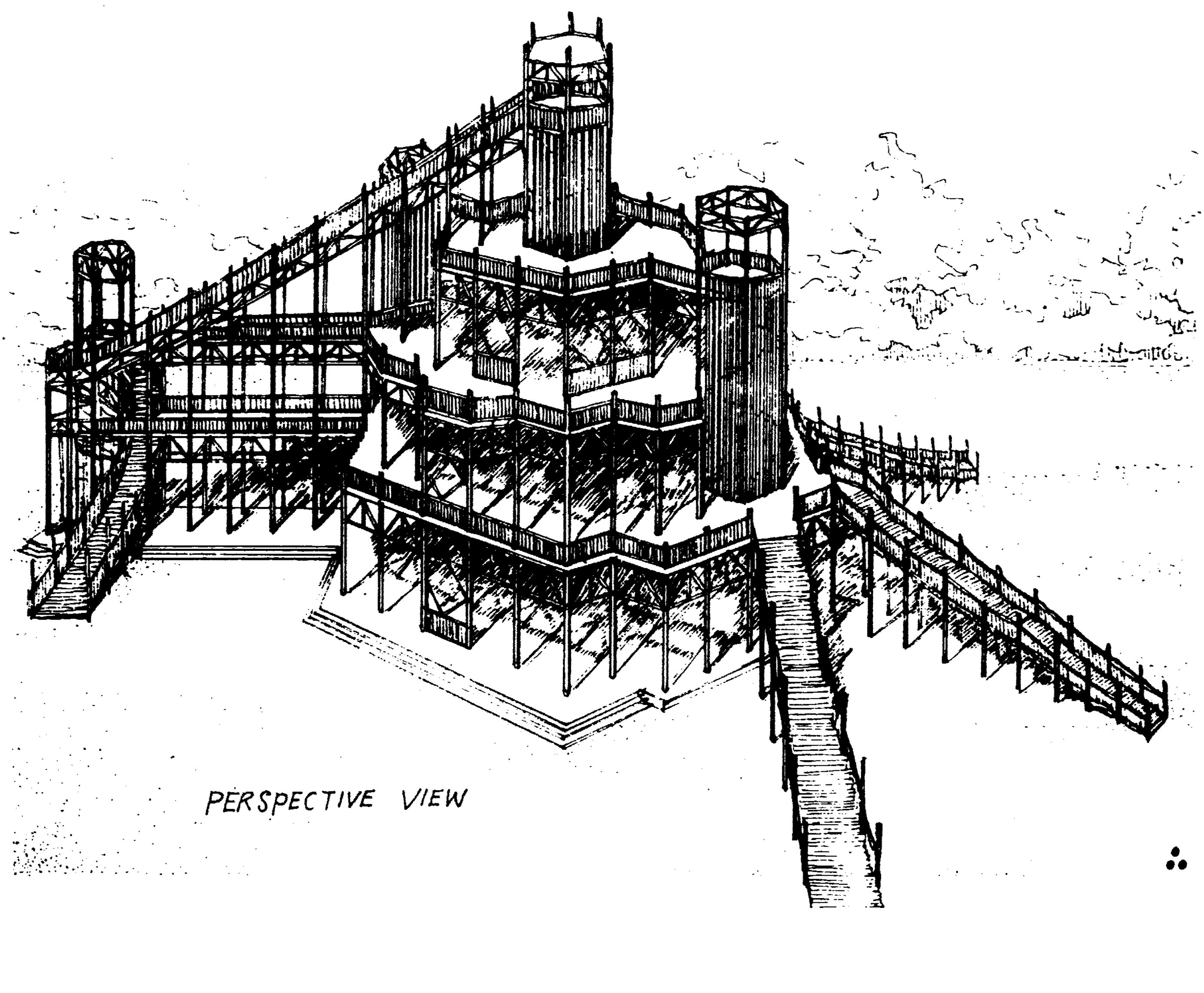
The following measures were taken preventing the bamboo from rot, crack and decay. i) The bamboo was cut over in the late autumn or early winter, ii) Insecticides was sprayed on ends of the bamboo. iii) The bamboo was strengthened by means of fire-baking and was cleared of any greasy dirt. This also brought the natural colour and lustre of the bamboo surface, iv) Bamboo strings are used in important sections to prevent the bamboo from cracking. v) Good care was taken of the bamboo material during transportation and storage to avoid deformity and damage.

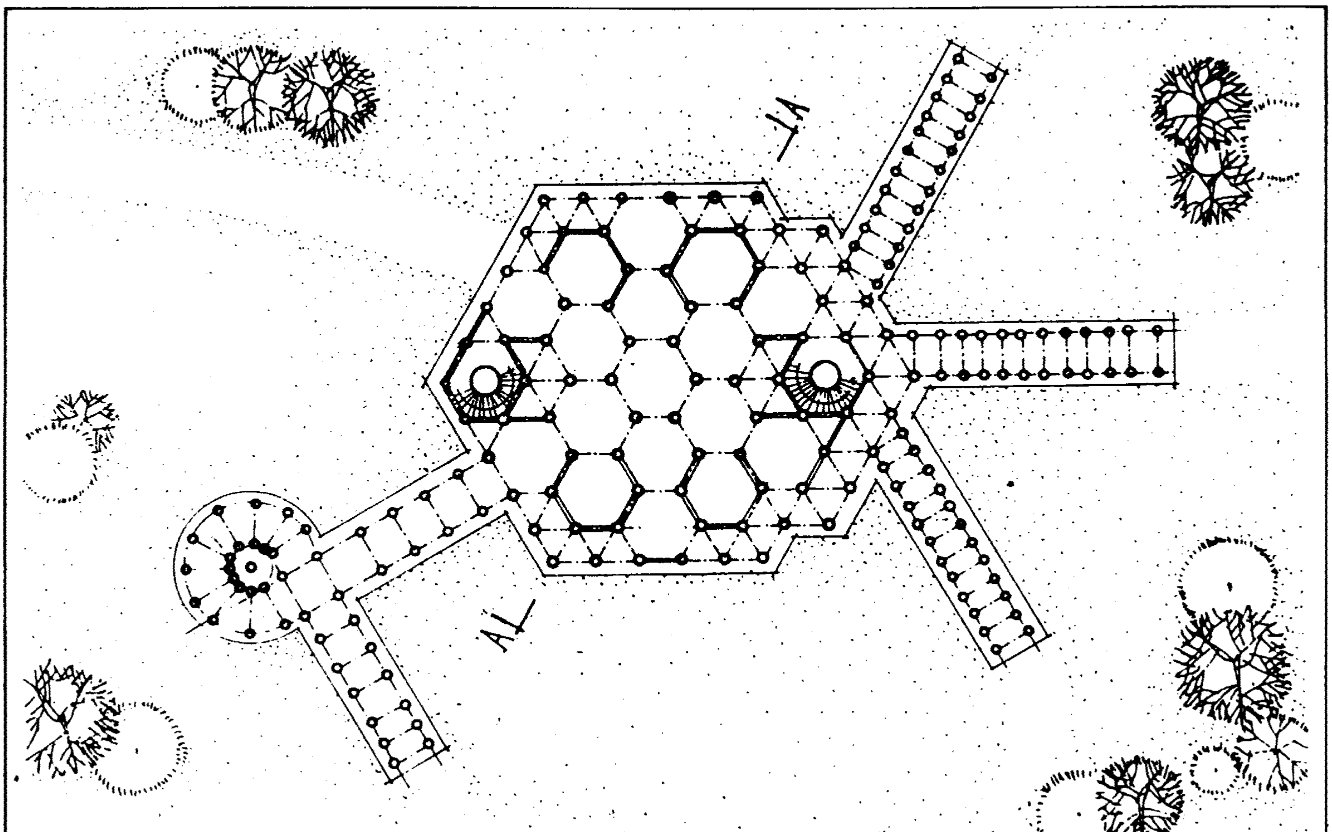
Main Points in the construction of the tower

The project involved all together 6,000 pieces of bamboo with over 100 mm in diameter, and 5,000 pieces of other kinds and dimensions. With a net weight of 120 tons all of the required bamboos was purchased and shipped to Zurich The selected bamboos were more than 4 years' old, straight and free of rot, The bamboo used was straightened and surface treatment carried. out prior to processing. The frames on processing were numbered, classified and packed in containers,

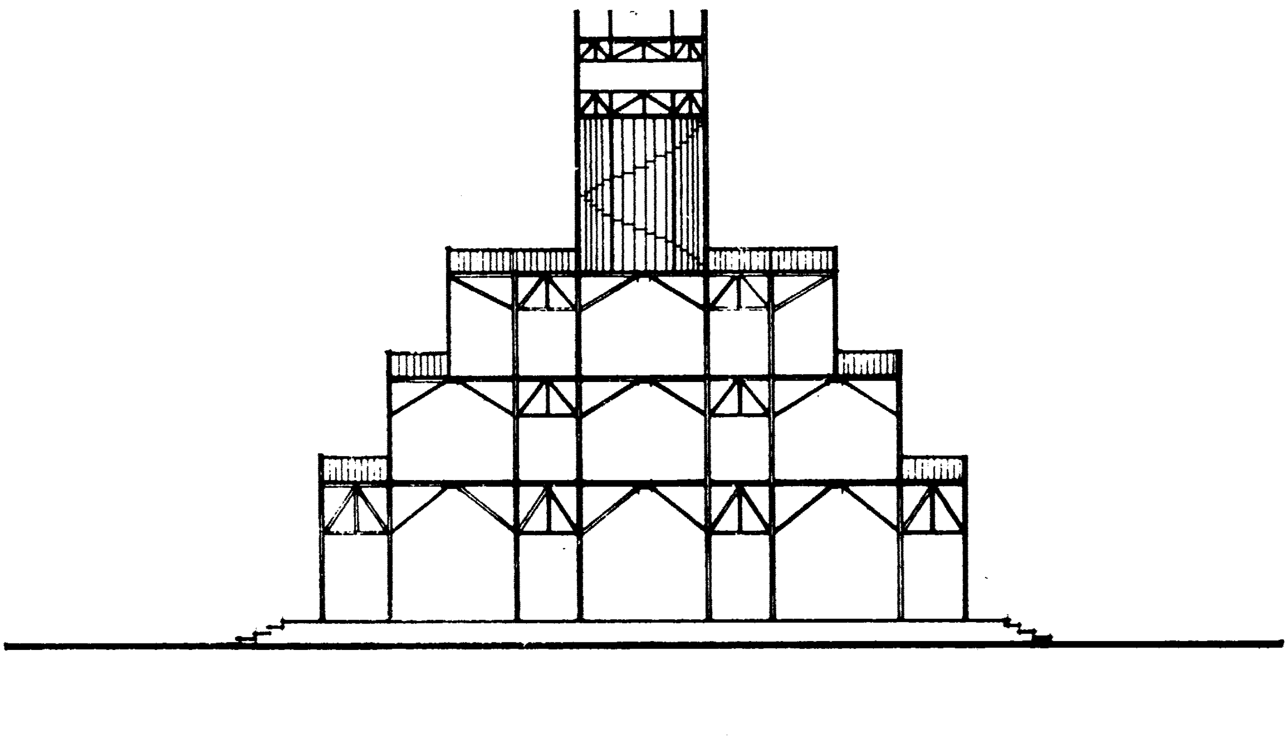
The large bamboo tower in Zurich was attractive and contructed by joining.

Mr Yang Benkuan and Mr Tian Jianong of our Institute, also participated in constructing the Bamboo tower.





PLAN of the BAMBOO TOWER
(Ground Floor)



A–A SECTION

A Study on Bamboo Cellulose Triacetate (B-CTA) Ultrafiltration Membranes

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Abstract

The methods for making B-CTA and C-CTA (cottqn-cellulose triacetate) ultrafiltration membranes and the factors affecting the membrane properties are described here. The storage of the membranes in 95% ethanol and H_2O_2 aqueous solution is mentioned. The results for trialof the membranes in pharmaceutical and food processes are also reported.

Introduction

Ultrafiltration (UF) is a new technique of membrane separation . The filtration process involves sieving effect and chemical behaviour of the substance on the surface of the membrane. Solvents and materials with low molecular weight pass through the membrane under a given pressure, and suspended matters and macromolecules are rejected, therefore the filtration, separation or purification of liquids treated are obtained. UF techniques were used only in laboratories before 1960. Various types of ultrafilters have been subsequently manufactured with the successful development of the UF membranes. UF has become an independent unit operation in chemical engineering. Widely used in food, chemical and pharmaceutical industries abroad. The applications of UF were tested in treatment of eiectrophoretic paints, purification of dyeing waste, separation and concentration of biological products and clarification of beverages in our country. Some of these tests have been applied in corresponding productions. It is important to choose and use membrane materials correctly with proper membrane-making technology according to the requirement of production and industry. It was more than 20 years since Loeb and Sourirajan successfully developed asymmetric CA membranes. Although other membrane materials have been widely studied by many membrane scientists during this period, to date CA is still the main membrane material at home and abroad, The main reasons for this are as follows: Compared with other membrane materials, the resource of raw material for CA is easily available and the price is cheap. The technology for making CA membranes is simple, and the membranes have good separation properties, are resistant to chlorine and non-toxic. However there are a few limitations for the applications. In order to expand the range of applications of CTA membranes, and to utilize the abundant bamboo resources, fully B-CTA ultrafiltration membranes with different pore size were made by the industrial Bureau of Suichang county, Zhejang Province.

Preparation Of Filters

1. Components of cast solution: Cotton-velvet CTA, B-CTA, acetone, Dioxane, methaiene dichloride, formamide, ethanol and water.

2. Preparation of cast solution: The CTA was dried in the oven at 105°C for about 1 hour, and the temperature droped to ambient. The CTA, solvents and additives were added in proper proportion into a glass flask with an agitator. The mixture in the flask was agitated for dissolution, then filtered and stilled to make it bubble free.

3. Preparation of membranes: The room for preparation of membranes was air-condi-

tioned and humidity-controfled. The cast solution was decanted into the slot of casting knife mounted on the casting machine, and the casting machine was allowed to run. The cast solution passed through the casting knife, and was spread into thin layers of solution under controlled solvent evaporation. After gelation in water bath, the wet UF membranes were formed. The dry UF membranes could be made when the wet membranes were treated with post-treatment agents.

4. Measurement of the membrane properties: The dry UF membranes were cut into proper size and shape, and mounted into ultrafilters. The water flux and cut-off of molecular weight were measured under given pressure, using distilled water and different protein solutions as feed respectively.

Results and Discussion

Membranes with good rejection and high flux are essential for the application of UF. The composition of cast solutions and the processing conditions in making the membranes are decisive factors for preparing UF membranes with good properties. We have made a comparison on the properties between the B-CTA and C-CTA membranes, and a systematic investigation of the effects of the membrane-making conditions on the properties of the membranes. These are summarized as follows:

1. Effects of contents of B-CTA and C-CTA in cast solution on properties of the membranes: For the last 20 years, asymmetric C-CTA membranes have been made in our laboratory but we do not have any knowledge of making B-CTA membrane. Through a series of experiments, it was found that B-CTA 84038 was suitable for making membranes. At the beginning, we prepared the B-CTA ultrafiltration membrane using the recipe for making C-CTA membrane.

The structure of the membrane as seen under electron microscope is shown in Fig. 1. The flux was low and the cut-off of molecular weight was also poor for these UF membranes. Therefore further experiments were made to determine proper composition of cast solution. The results are summarized in Table 1.

The properties of the UF membranes for the two kind of CTA were basically similar after dozens of sifting test, and their microstructures were also similar (Fig, 2).

2. Effect of additive contents on the membrane properties: The results are summarized as shown in Table 1. Both kinds of additives and the different amounts of the same additive have a great influence on the dissolvable state

Table 1. Effect of contents of B-CTA and C-CTA in cast solution on the membrane properties.

B-CTA 84038 (Wt%)	C-CTA 82855 (Wt%)		Flux (ml/cm^2 hr)	
5	5	490	760	472
6	4	462	692	644
7	3	442	708	580
8	2	438	668	512
9	1	414	448	452
10	0		708	710
0	10		738	716
Temperature of feed water	(°C)	10	14	10

Measurement apparatus: Ultrafilter with effective membrane area 10 cm^2
Measurement conditions: Operating pressure 3 kg/cm^2. feed tap water.

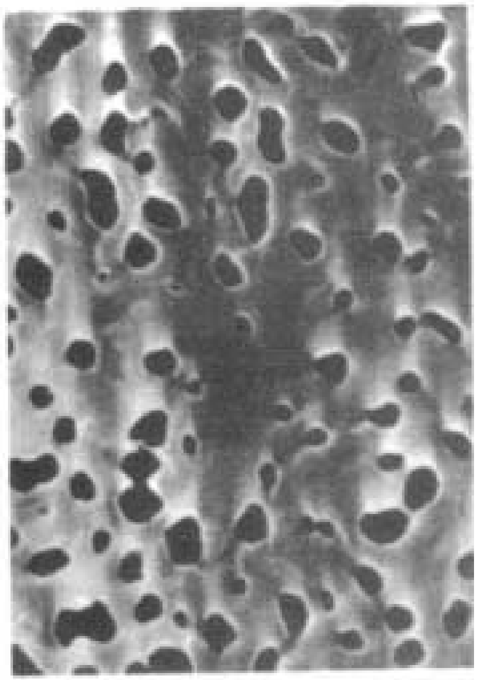

Fig. 1. Electron micrograph of B-CTA ultrafiltration membrane (3000 x)

of cast solution. It is therefore very important to choose a proper additive as a pore-forming agent in making UF membrane with excellent properties. It was found that the mixture of formaldehyde and ethanol was a suitable additive for B-CTA after a lot of times in sifting the additive. The effect of the additive contents on the membrane properties is shown in Table 2,

It can be seen from Table 2 that water flux was increased with the increase of additive content. When the ratio of the additive in cast solution was more than 70 %, it was hard to dissolve the polymer, Various membranes

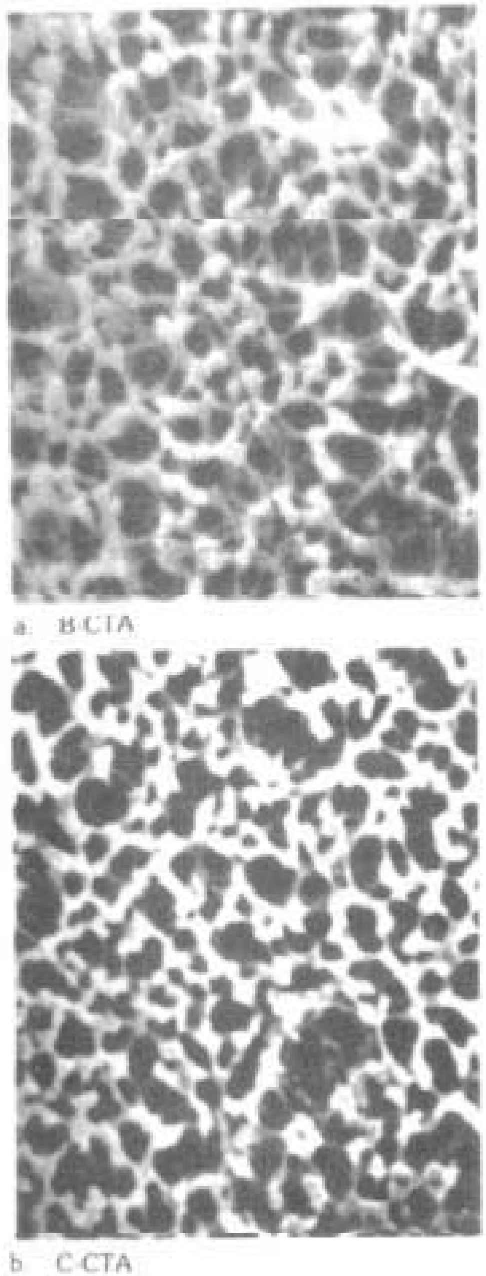

Fig. 2. Electron micrographs of B CTA and C CTA ultrafiltration membranes (10,000 x)

Table **2. Effect** of additive contents on the membrane properties,

Additive content (Wt%)	15	20	25	30	35	40	45
Water flux (ml/cm² hr)	21	174	216	276	306	408	495
Additive content (Wt%)			50	55	60	65	70
Water flux (ml/cm² hr)			504	585	714	798	856

Temperature of feed water: 9°C
Other measurement conditions are the same as in Table 1

a. Dense skin layer of the niembrane with low flux (2000 ×)

b. Loose skin layer of the membrane with high flux (2000 ×)

Fig. 3 Electron micrographs of skin layers of two different UF membranes.

with different water flux can be made to satisfy the requirements of corresponding applications.

3. Effects of membrane-making conditions on the properties of membranes: There were many great differences in properties of the membranes which were prepared from the same cast solution, hut under different membrane-making conditions. More dense membranes with lower flux were formed under certain conditions, but the membrane with high flux and large pore size could be obtained by changing some of these conditions. The microstructures of the two kind of membranes are shown in Fig, 3,

(i) Effect of gelation temperature on membrane properties* The more important step for preparation of UF membrane from cast solution is to dip the just-cast membrane into water ~ the gelation medium The exchange rate between water, solvent and additive is faster in water with high temporatures than at low. The pore size and water flux of the membrane obtained from the bath at high temperatures are higher than those from the bath at low temperatures The expcenmental results are listed in Table 3.

As may be seen from Table 3, the exchange rate between water, solvent and additives increased with the increase of temperature. The flux reached maximum at the gelation temperature of about 30° The membranes became denser and their flux were also low when the gelation temperature was higher than 30°C, this might be caused by the change of gelation mechanism.

(ii) Effects of increasing temperature and time on the membrane properties: The UF membranes need to be sterilized at high temperature when they are used for purification and separation in pharmaceutical and food processes. Thus the membranes were put into hot water at different temperatures for a certain period to test the changes of their properties, The results are shown in Tables 4 and 5.

Table 3. Effect of temperature of gelation medium on the membrane properties.

Gelation temperature (°C)		Water flux (ml/cm^2 hr)
0.5	304	300
5	428	420
10	508	504
15	548	540
20	680	628
25	844	780
30	1074	1062
35	828	720

Measurement conditions: temperature of feed water 6°C other conditions are the same as in Table 1

Table 4. Effect of increasing temperature on the membrane properties.

Annealing temperature (°C)	30	40	50	60	70	80	90	loo
Water flux (ml/cm^2 hr)	840	824	680	672	592	580		548
Water flux (ml/cm^2 hr)	956	912	686	786	762	568	540	512

- The annealing period: 30 min.

Table 5. Effect of annealing on the membrane properties

Annealing period (hr)	0.5	1.0	2.0
Water flux (ml/cm^2 hr)	540	386	342

- The annealing temperature; 100°C.

It was obvious that the flux of the membrane decreased with the increase of annealing temperature. Because annealing is a process of "dehydration and shrinkage" of the membrane. UF membranes with different properties (flux, pore size and surface structure) could be prepared by adjusting annealing temperature.

The flux of the membranes decreased and the strength of membranes increased with extension of annealing period, indicating contraction of the pore sizes in the membranes. The flux of the membrane was still acceptable after annealing of the membrane at lOO°C for 2 hours.

(iii) Effects of the concentration of plasticizer and drying temperature on the membrane properties: Dry membranes are convenient for storage, transportation and operations in the manufacture of modules, and bacteria was also eliminated in the dry membranes. The membranes dried naturally at ambient condition were brittle and poor in strength. The reason for this might be the large surface tension between water and the wall of pore in the membrane: and crevices were then created at the wall of the pore after water evaporated from these pores. If the action between water and CTA is decreased by lowering the surface tension between them,

Table 6. Effect of plasticizer concentration on the membrane properties.

Plasticizer concentration (Wt%)	0	10	15	20	25	30	35
Water flux (ml/cm^2 hr)	768	936	748	736	624	580	868
	852	702	630	570	668	812	652
	676	472	560	744	1075'	548	612
	644	368	528	723	1023 .	516	524
apperance of the membrane	dry and white, brittle and breakable		Flexibility of the membrane is increased with the increase of glycerol concentration. Usually 15-20% glycerol was chosen for drying membrane.				

- Temperature of feed water: 78°C. other temperature: 12°C.

the loss of water in the membranes does not cause the cracks on the pore wall. We tested a few surfactants and plasticizers, and finally glycerol was chosen as plasticizer, as it is non-toxic and suitable for food and pharmaceutical processes. Table 6 shows the effect of concentration of plasticizer on the properties of membrane.

The drying of the membranes was faster at high temperature's than at low. Effect of drying temperature on the membrane properties was tested in order to find a proper combination between drying temperature and period for casting membrane continuously by machine. The results are given in Table 7.

It can be seen from Table 7 that drying temperature only had a slight influence on the properties of the membrane. Drying temperature at 60-70°C was chosen for convenient operation, and the membrane could be dried in 5-10 minutes at this range of temperature.

(iv) Storage experiment: In order to satisfy the requirements in food and pharmaceutical industries, the membranes were dipped into 95% ethanol and medical H_2O_2 aqueous solution for a certain period to see the change of membrane properties. The results are shown in Table 8.

Table 8 shows that there was no change in the properties of B-CTA ultrafiltration membrane after storing them for more than 3 months under the above conditions.

(v) Effect of feed temperature on the membrane properties: UF membranes have high flux. The operating conditions, such as feed temperature, etc, have a great influence on the membrane properties. The effect of feed temperature on membrane flux was tested with tap water as feed. The results are given, in Table 9.

As shown in Table 9, the flux increased with the increase of feed temperature. This is because the viscosity of water at high temperature is smaller than that at low temperature, and the resistance to water passing through the membrane also shows the same trend.

4. Trial of B-CTA ultrafiltration membrane in food and pharmaceutical processes: There are no phase change and thermal effect in UF process and therefore UF process plays a very important role in food and pharmaceutical industries. For example, in UF of beverages, the impurities are removed, bacteria eliminated and the colour, flavour and nutrients of the beverage are preserved, making the beverage more tasty. The preliminary results on UF of wines are shown in Table 10.

Table 7. Effect of drying temperature on the membrane properties.

Drying temperature (°C)	9	30	40	50	60	70	80	110	126	142
Water flux (ml/cm^2 hr)	248	452	384	400	393	450	462	–	–	–
	476	363	–	–	–	360	336	336	318	544

Table 8. Effect of storage on membrane properties under different conditions*

Date of measurement	April 15, 1985	May 6, 1985	July 18. 1985
Flux of membrane stored in 95% ethanol (ml/cm^2 hr)	226	224	216
Flux of membrane stored in medical H_2O_2 aqueous solution (ml/cm^2 hr)	219	218	210
Flux of dried membrane (ml/cm^2 hr)	248	–	250

- The flux of wet membrane: 248 ml/cm^2 hr measurement conditions are the same as in Table 1.

Table 9. Effect of feed temperature on the membrane properties.

Feed temperature (°C)	7	15	30	50	78
Water flux (ml/cm^2 hr)	339	447	672	1278	1872

Table 10. Ultrafiltration of wines.

name	corn alcohol	sorghum wine	hangzhou	Xiangqu
before UF	There are flaked coagulants at 50°	Flaked coagulants and black precipitants present	Grey and black precipitants	Milky white and grey particles
after UF	Clear bright	Clear transparent tasty	clear transparent tasty	tasty no particles

In addition, UF was used in glucose infusion and the maximum of finished product was raised from original 85%) to 99%. According to the results reported elsewhere, UF was successfully used in food, pharmaceutical, chemical engineering and electronic industries. UF will also be widely used in the production of ultrapure water, separation in chemical engineering, pharmaceutical and food, industries in our country.

Conclusion

Experiments were carried out to compare the properties of C-CTA and B-CTA ultrafiltration membranes.

The properties of B-CTA ultrafiltration membrane are similar to that of C-CTA.

B-CTA with degree of polymerization 300 can easily be dissolved, but the conditions for making membranes are more severe.

Cast solution of B-CTA is clear and transparent. B-CTA is slightly better than C-CTA in resistance to acids and alkali. so the range of application for B-CTA ultrafiltration membrane is wider than that of C-CTA.

Traditional Preservation of Bamboo in Java, Indonesia

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Abstract

The traditional method of bamboo preseruation by immersion in water, followed by the rural Javanese is adequate. The immersion for a *month* decreases *the starch content of the treated bamboos and provides considerable resistance against the powder post beetle, Dinoderus minutus and D. brevis. The Javanese felling season "mangsa" XI helps to* prevent *damage by beetles.* Traditional *preservation of Dendrocalamus asper indicates an improvement in the resistance. On Gigantochloa apus and G. atter the* effect *is insignificant,* but these two bamboo *species have the least starch contents and highest degree* of *resistance. The immersion treatment does not work sufficiently for Bambusa vulgaris due to its high content of* starch. *The* treated bamboos indicate *a considerably better performance at least for one year.*

Introduction

Bamboo is an important, cheap, and plentiful resources in Indonesia. It could be found almost everywhere, mostly in the islands of Java and South Sulawesi, consisting of more than 30 species, distributed geographically up to 2000 m above sea level (Hildebrand, 1954). A survey conducted in the Province of Yogyakarta on 30 "kecamatan" indicated that bamboos grow everywhere, planted by the rural communities (Haryono Danusastro et al., 19'79; 1980; 1981). It has been observed that 13 species of bamboo are grown by rural people in their homeyards; four of which have been most extensively used, especially for construction purposes, i.e., *Gigantochloa apus* Kurz, *G. atter (Hassk.) Kurz ex* Munro, *Dendrocalamus asper Back., and Bambusa* sp. (Abdurachim, 1967; Hildebrand, 1954; Heyne, 1950; Widjaya, 1980). Utilization of bamboos for construction is about 13% in the rural areas of the provinces of Yogyakarta, Central Java, East Java, and Bali; its role increasing to 30% for residential building construction; it is used for roofing, partition wall, and ceiling frames (Anon., 1977; Anon., 1982) .

Bamboo is more susceptible to biodeteriorating agents as compared to timber, such as fungi, termite, and especially insect borers (Liese, 1980). Among the insect borers observed in his study, Sulthoni (1981; 1983a) considered powder post beetles *Dinoderus minutus* Fab. and *D. brevis* Horn. the most damaging.

Untreated bamboos used in open places and on ground are generally destroyed in about one or two years (Varmah and Pant, 1981). Treatment of bamboos with preservatives is widely regarded as necessary, but however it is seldom carried out; the reasons are a lack of knowledge about possible use of chemical preservatives, the uncertainty about the advantage of bamboo preservation, and the lack of market for treated bamboos (Liese, 1980).

Preservation Of Bamboo

Two methods of preservation could be done either chemically or non-chemically. Chemical treatment of bamboo using preservatives could be applied on dry or green or fresh bamboos, and some techniques for preservation are the following (Tewari and Bidhi Singh, 1979) :

1. **Washing and coating:** A variety of coatings such as tar, lime wash, tar and lime wash, and tar sprinkled with sand are used in Indonesia by house builders. These coatings are successful only when continuously done on cut surfaces, exposed internodes, abrasions and splits.

2. **Brushing, swabbing, spraytng and dippling:** These surface treatments are for temporary protection of bamboo in storage or before it is given impregnation treatments. Various chemicals used are aqueous emulsion of insectisides like dieldrin 0.03%, aldrin 0.015%, or D.D.T. 7-10% in kerosene oil. In Japan, mercury and tin salts have also been used for protection against borers and fungi respectively. Other chemicals such as sodium pentachlorophenate, borax and boric acid are also used.

3. **Soaking:** Air-dried bamboos have only to be submerged in the preservative solution (oil or oil solvent type) for a period depending upon the species, age, thickness and absorption required. The penetration is predominantly by capillarity. The soaking method requires little equipment and technical knowledge, provided the schedule of treatment, such as type of preservatives, their concentration and the period of dipping, is worked out. The absorption of preservative is more in half round specimens in comparison to round ones.

4. **Boucherie process:** In normal Boucherie process the Bamboo is treated by preservative through gravity from a container placed at a height. In India this method was modified later on by using a simple hand pump. By means of air pressure of 1.0 to 1.4 kg/cm^2 applied to the preservative container, the preservative is pushed through the tissues of the green bamboo. This modified procedure reduces the period of treatment significantly and under the pressure the treating solution forces the sap out of the walls and septa of the bamboo through the open end and replaces it in course of time.

The penetration and absorption of the preservative depend upon several factors, such as concentration, treatment time, nature of chemical used, age and dimension of the bamboo, moisture content, etc.

5. **Steeping method:** This method generally consists of allowing freshly cut culms, with the crown and branches intact, to stand in a container holding the preservative solution to a depth of 30 to 60 cm. Through leaf transpiration current, the solution is drawn up to the stem. The period of treatment depends upon the species, the length of the culm, weather conditions, preservative used, etc.

6. **Sap displacement method:** Green round or split bamboos are immersed partly in water based preservatives. The preservative rises gradually to the top through absorption due to replacement of the sap.

7. **Hot and cold bath process:** When pressure facilities are not available, the hot and cold bath or open tank process can be applied for dry bamboos similarly to that used for timber. Absorption of creosote up to 70 kg/m^3 is reported to have been obtained by this process. Research studies at the Forest Research Institute, Dehra Dun indicate that the period of heating significantly influences the absorption of the preservative. By increasing the heating period from 1 hour to 6 hours, the absorption increases'upto 100%.

8. **Diffusion process:** This process can be employed using water soluble preservatives, either in the form of solution or paste to treat green bamboos.

In this process the toxic chemicals diffuse from the place of application at high concentration to other zone through the water medium. With enough time the chemical preservative spreads to almost the entire volume of the green material. This diffusion process appears most suitable in the case of bamboos which are difficult to impregnate under pressure in dry conditions. This process requires simple equipment and are popular in many countries such as Germany, Canada, U.S.A., Australia and New Zealand. It appears that permeability of bamboo to preservatives is significantly increased after ponding. Though the service life of the bamboos treated by any process mentioned earlier may not be equal to that obtained by pressure and open tank method (where greater degree of quality control is possible), yet the method is cheap, simple and requires simple equipment, applicable even in remote areas and further-gives reasonably good protection to the treated bamboos.

9. **Pressure processes:** Pressure process is suitable for treating dry bamboos. When the bamboo moisture content is reduced below 20%, satisfactory penetration and absorption is obtained by this process. The drying of bamboos is generally carried out in the air under cover. To prevent deterioration of bamboos during drying, it is important to impart prophylactic treatment with suitable chemicals. For the installation of pressure treatment plants, heavy investment is usually required which the average in user cannot afford.

Cracks are usually developed in bamboos if treated under high pressure which reduces their strength. It has been observed that species having thin walls are susceptible to cracking when treated under low pressures (5-7 kg/cm^2). Round specimens of Dendrocalamus strictus treated under high pressure of 14.06 and 28.12 kg/cm^2 absorbed 88.12 and 107.00 kg/m^3 of creosote-fuel oil mixture respectively, while half split specimens absorbed 91.54 and 108.81 kg/m^3 of the preservative.

Traditional Preservation of Bamboo

Insect borers such as powder post beetle are a serious problem. These included Dinoderus minutus Fab., D. ocellaris Steph., and D. brevis Horn., which is popularly known as bamboo "ghoon" in India (Beeson, 1961; Sen Sarma, 1977 and "bubuk bambu" in Java Kalshoven , 195 1).

A non-chemical traditional method of preservation is practised quite often in the Asian countries to prevent bamboo against powder post beetle. This method is applied by soaking the cut bamboo culm under the water. It costs almost nothing and can be carried out by the rural people themselves without any special equipment, It is more suitable for the reasonably cheap and easily available bamboo raw materials (Liese, 1980).

The susceptibility of bamboo to borer attacks depends on the species, its starch content, age of the culm, felling season, and the physical properties of the bamboo (Plank, 1950). But further studies indicate that starch content in bamboo is an important factor influencing the susceptibility to borer (Plank, 1950; 1951); the damage caused by the borer has been found proportional to the starch content of the bamboo (Purushotham. et al., 1953; Beeson, 1961; Liese, 1980; Tamolang et al., 1980; Sulthoni, 1984).

Plank (1950) and Beeson (1961) observed that during the soaking period in the water, the starch contents of the bamboo tissue is reduced. It is therefore said to be less attractive thereby improving the resistance level against borers (Liese, 1980; Tamolang et al., 1980). This assumption, however, remains to be proved because not much is known about the real effectiveness of this traditiona! method of preservation (Liese, 1980) .

The rural Javanese have been traditionally practicing this method of bamboo preservation; not only by soaking the half-finished bamboo materials in the water or muddy water, but also in determining the best felling season of the selected bamboo species. They cut the bamboos for their use at a certain season what they call "mangsa tua", which they believe to be the most appropriate time, to obtain better quality of bamboos such as Gigantochloa *apus* and G. after, used for constructions. The Javanese have their own seasonal calendar what they call "pranatamangsa" (the rule of season). It is actually a solar calendar system, but explicitly ecologically oriented to be in harmony with the sequence of their agricultural activities. During the year there are two main seasons (dry and rainy), which are further divided into four detailed seasons, i.e., "marengan" (pre-dry season, 88 days before the real dry season), "katiga" (88 days of real dry season), "labuh" (pre-rainy season, 95 days before the real rainy season), and "rendengan" (94 or 95 days of real rainy season). Each detailed season is divided into 3 "mangsa". but with uneven number of days within each "mangsa". Mangsa I – VI is grouped as "mangsa muda" (young season) and mangsa VII – XII as "mangsa tua" (old season) (Daldjoeni, 1983).

Justification of the Javanese Traditional Method of Bamboo Preservation

Research has been conducted by the present author, supported by IDRC on this subject (Sulthoni, 1983b). The main goal of the study was to support with scientific reasons the rural Javanese tradition in handling bamboo for longer service life against powder post beetle Dinoderus sp.

Two specific objectives were formulated, to, quantify scientifically the time of felling "mangsa tua", and to assess the efficacy of the effect of water immersion of bamboo in improving the resistance performance against borer.

Four species of bamboo were used: 1. Gigantochloa apus. the most favoured for construction. 2. G. otter. specifically favoured for furniture and musical instruments. 3. Dendrocalamus asper, indefinite, but occasionally favoured for poles due to its tallness. 4. Bambusa vulgaris. minor value and not favoured for constructional purposes.

The first objective of the research was to justify whether the fluctuation of the natural relative population of the borer synchronized the best felling season of the "mangsa tua". The favoured and not favoured bamboo species were studied by determining the starch contents of the monthly consecutive felling of the bamboo samples, and the corresponding degree of susceptibility.

The second objective was to determine the decrease of the starch content of the immersed bamboo samples in water for various immersion periods, and hence to evaluate their corresponding degree of borer attacks. Southwood method (1978) was used to measure the natural relative population of the borer. while Humphrey's and Kelly's method (1961) was used to determine the starch contents of the bamboo species. The degree of susceptibility in the bamboo species against attacks was assessed using the method of Beeson (1961) by counting the borer's hole per sample.

Results Of The Studies

1. Felling season of bamboo: The relative population level of the borer Dinoderus minutus and D. brevis has a tendency to decrease in the "mangsa tua", and the lowest in "mangsa" XI (April 20 – May 11) (Table 1). Mangsa XI is the best season the Javanese use to cut the bamboos for their own use. In terms of the biological process of the bamboo clumps, "mangsa" XI is about the end of the sprouting period of the shoots. Felling the mother bamboo at this time is not damaging to the shoots.

Mangsa XII is actually the last "mangsa" of the "mangsa tua", but the rural people considered it too late to cut bamboos. In Table 1 it can be observed that the population of the borer increases considerably.

It is concluded from the data in Table 1, that the felling period followed by the Javanese rural people can be recommended.

2. Selection of better quality of bamboo species: It has been mentioned earlier that the rural people in Yogyakarta, Java, prefer Gigantochloa apus and consider Bambusa vulgaris as of minor quality. Table 2 shows the average highest starch content in B. vulgaris, which fluctuates between 0.48 up to 7.97% within a year. In G. apus and G. atter it fluctuates between 0.24 to 0.71% and 0.24 to 0.64% respectively. The degree of susceptibility that the four bamboo species indicate is proportional to their respective starch contents (Table 3). B. uulgaris shows 0.12 to 13.87 boring holes per sample. while G. apus and G. atter show the most resistant with boring holes of 0 to 0.81 and 0 to 1.25 respectively. D. asper has its susceptibility degree between B. uulgaris and Gigantochloa. with its starch contents fluctuating between 0.27 – 2.80% and boring holes between 0 and 5.56. It is clearly proved therefore, that classification followed by the rural people is scientifically justified.

3. Effect of water immersion on split bamboo: The results of the study are shown in Tables 4. 5, and 6. with different periods of immersion of one. two and three months. The data in the three tables are self explaining: all treatments are effective in improving the degree of resistance in the bamboo treated. either in running or stagnant water or mud. and the periods of immersions. It is concluded that one month immersion is enough. Bamboo species with less than 1% starch content is considered as good quality bamboo useful for construction.

4. Service life of water-immersed bamboo: Traditional preservation has indicated to improve the resistance performance, but it depends primarily on the bamboo species. One year of service life of the treated bamboo species is indicated in Table 7. In B. *vulgaris* the service life is still poor and this is due to its high content of starch. D. asper on the other hand indicates good performance.of one year service life with only 2.08 holes of borer attacks. G. apus and G. after show the best, even on the control specimen. It is again a stronger indication that least starch contents in the two latter species promotes better quality.

Table 1. Fluctuation of the relativepopulation of Dinoderus beetle in the campus area ofGadjah Mada University Yogyakarta. Indonesia (113 m above sea level. tempemture range max. 30-30°C, humidity range max. 75-90% at 2.00 p.m.

Months	Relative pobulation of power post beetles related to months			Javanese "mangsa" and days		Relatrve populatron of power post beetle related to "mangsa"		
	a	b	C			a	b	C
June. 1980	591	439	116	XII	(May 12 – June 21) (41-t	515	380	8 6
July. 1980	461	82	30	I	(June 22 – Aug. 1 I (41)	551	143	45
Aug. 1980	490	63	17	II	(Aug 2 – Aug. 24) (23)	416	53	lb
Sep., !980	293	119	19	111	(Aug 25 Sept. 19) (24)	223	94	32
Oct . 1980	413	164	12	IV	(Sept 18 Oct 12) (25)	220	46	9
Nov. 1980	610	189	11	V	(Oct. 13 – Nov 8) (27)	625	194	12
Dec . 1980	230	138	6	VI	(Nov 9 – Dec 21) (43)	4 %	246	10
Jan . 1981	105	88	4	VI1	(Dec 22 Feb 2 I (43)	172	128	
Feb.. 1981	155	6	0	VIII	(Feb 3 – Feb 28) (26)	136	6	0
Mar. 1981.	250	219	1	IX	(Mar 1 – Mar 25) (25)	206	198	0
Apr. 1981	93	130	1	X	(Mar 26 – Apr 19) (24)	115	126	2
May. 1981	10	lb	0	XI	(Apr 20 – May 11) (23)	26	39	0
Total	3 701	1 653	217			3 701	1 653	217

Notes: a -- *Dinoderus minutus* and *D. brevis* (Fam. Bostrychidae)
b -- *Conarthrus praeustus*, *G. filiformis* and *Myocalandra exarata* (Fam. Curculionidae)
c -- *Laemotmetus rhizophagoides* (Fam. Passandridae)

Table 2. Average starch content (%) of four bamboo species, based on 12 consecutive monthly fellings.

Felling months	B. vulgaris			D. asper			G. apus			G. atter		
	b	m	a	b	m	a	b	m	a	b	m	a
May, 1980	4.39	3.86	4.00	0.72	0.81	1.18	0.46	0.39	0.28	0.63	0.54	0.42
June, 1980	2.77	2.83	5.49	0.41	0.78	0.49	0.29	0.31	0.31	0.49	0.43	0.33
July, 1980	0.83	3.42	1.63	0.29	0.31	0.60	0.32	0.47	0.37	0.31	0.30	0.29
Aug., 1980	1.33	2.87	3.80	0.27	0.27	0.85	0.27	0.32	0.28	0.54	0.44	0.64
Sept. 1980	2.61	3.61	4.53	1.40	2.01	2.80	0.27	0.32	0.24	0.33	0.25	0.24
Oct.. 1980	3.55	4.21	6.44	0.35	0.50	0.63	0.26	0.27	0.26	0.29	0.29	0.38
Nov., 1980	5.22	5.49	7.97	0.29	0.42	0.66	0.25	0.53	0.71	0.28	0.33	0.34
Dec.. 1980	2.31	2.56	3.59	0.26	0.51	0.67	0.25	0.32	0.36	0.30	0.32	0.39
Jan.. 1981	0.48	0.51	0.52	0.34	0.48	0.62	0.25	0.27	0.27	0.31	0.34	0.33
Feb.. 1981	0.65	1.60	2.39	1.06	1.17	1.48	0.35	0.31	0.27	0.33	0.24	0.35
Mar., 1981	2.62	3.63	5.62	2.32	2.52	1.42	0.31	0.27	0.26	0.44	0.34	0.31
Apr., 1981	1.32	1.66	3.00	0.31	0.33	0.32	0.30	0.46	0.49	0.33	0.31	0.54

Notes: b – basal part of culm
m – middle
a – apical
All bamboo samples are about two years old

Table 3. Average Dinoderus beetle attacks (in number of holes) of four bamboo species, based on 12 consecutive monthlyfellings, corresponding to the related starch contents shown in Table 2.

Felling months	B. vulgaris			D. asper			G. apus			G. atter		
	b	m	a	b	m	a	b	m	a	b	m	a
May. 1980	13.87	10.50	6.50	0.15	1.43	5.56	0	0	0	0.06	0.06	0
June, 1980	4.63	5.32	2.12	0.06	1.06	1.62	0	0	0	0.18	0	0
July, 1980	4.75	4.68	3.06	0.06	0.18	1.00	0.18	0.18	0	0	0	0
Aug., 1980	7.37	6.37	3.18	0	0.18	0.06	0	0	0	0	0.12	0.12
Sept. 1980	5.37	2.87	1.93	4.25	2.43	4.00	0	0	0	0	0	0
Oct., 1980	7.37	7.81	4.37	3.00	3.62	3.06	0	0	0	0	0.06	0
Nov., 1980	8.43	11.06	5.31	0.81	0.75	0.12	0.25	0.62	0.81	0	0	0
Dec.. 1980	5.43	6.37	4.18	1.25	1.43	1.62	0.06	0	0.06	0.18	0.06	0.12
Jan., 1981	3.93	0.44	4.62	2.00	2.62	2.62	0	0	0	0.62	1.25	0.81
Feb., 1981	3.25'	1.68	2.00	1.87	2.87	0.87	0	0	0	0.43	0.75	1.06
Mar., 1981	1.18	2.93	1.81	5.25	4.43	3.25	0.06	0	0	0.25	0.18	0
Apr.. 1981	0.12	0.37	0.18	0	0	0	0	0	0	0	0	0

Notes: b – basal part cf culm
m – middle
a – spical
All bamboo samples are about two years old.

Table 4. Starch contents and the corresponding powder post beetle attacks of 4 bamboo species after 1 month immersion in water.

Bamboo species	Immersion treatment	First felling		Second felling		Third felling	
		a	b	a	b	a	b
1. B. vulgaris	Control	4.09	45	3.69	39	1.96	28
	Running water	3.16	19	3.48	4	1.50	1
	Stagnant water	3.39	16	3.38	0	0.33	11
	Mud	3.31	16	3.29	0	1.61	5
2. D. asper-	Control	0.90	6	0.56	12	0.40	1
	Running water	0.33	0	0.55	0	0.35	0
	Stagnant water	0.47	0	0.42	0	0.39	0
	Mud	0.48	0	0.40	0	0.36	0
3. G. apus	Control	0.37	0	0.30	0	0.38	3
	Running water	0.30	0	0.25	0	0.35	0
	Stagnant water	0.23	0	0.32	0	0.26	0
	Mud	0.33	0	0.32	0	0.38	0
4. G. atter	Control	0.53	2	0.41	4	0.30	1
	Running water	0.33	0	0.28	0	0.30	0
	Stagnant water	0.39	0	0.28	0	0.29	0
	Mud	0.29	0	0.40	0	0.26	0

Notes: a – Starch contents in percent
b Powder post bettle attacks in number of holes after 1 year exposed in open
All bamboo samples are about two years old

All bamboo samples are about two years old. (The results presented in Table 4 and 5 are for the same treatment Eds)

Table 5. Starch contents and the corresponding powder post beetle attacks of 4 bamboo species after 2 months immersion in water.

Bamboo species	Immersion treatment	First felling		Second felling		Third felling	
		a	b	a	b	a	b
1. B. vulgaris	Control	4.09	45	3.69	39	1.96	28
	Running water	2.70	0	2.83	1	1.38	2
	Stagnant water	2.87	1	3.28	8	0.27	2
	Mud	3.35	2	2.98		1.39	0
2. D. asper	Control	0.90	6	0.56	12	0.40	1
	Running water	0.32	0	0.40	0	0.31	0
	Stagnant water / Mud	0.28 / 0.33	0	0.25	0	0.31 / 0.33	0
3. G. apus	Control	0.37	0	0.30	0	0.38	3
	Running water	0.28	0	0.23	0	0.27	0
	Stagnant water	0.26	0	0.32	0	0.21	0
	Mud	0.35	0	0.24	0	0.28	0
4. G. atter	Control / Running water	0.36 / 0.25	2 / 0	0.24 / 0.25	4 / 0	0.30	0
	Stagnant water	0.30	0		0	0.25	0
	Mud	0.30	0	0:27	0	0.22	0

Notes: a – Starch contents in percent
b – Power post beetle attacks in number of holes after 1 year exposed in open
All bamboo samples are about two years old.

Table 6. Starch contents and the corresponding powder post beetle attacks of 4 bamboo species after 3 months immersion in water.

Bamboo species	Immersion treatment	First felling		Second felling		Third felling	
		a	b	a	b	a	b
1. B. vulgaris	Control	4.09	45	3.69	39	1.96	28
	Running water	2.46	1	1.70	0	0.52	1
	Stagnant water	3.27	0	1.91	1	0.23	13
	Mud	3.27	0	1.58	0	1.05	0
2. D. asper	Con trot	0.90	6	0.56	12	0.40	1
	Running water	0.31	0	0.39	0	0.25	0
	Stagnant water	0.25	0	0.24	1	0.20	0
	Mud	0.33	0	0.22	0	0.24	0
3. G. apus	Control	0.37	0	0.30	0	0.38	3
	Running water	0.29	0	0.22	0	0.24	0
	Stagnant water	0.26	0	0.24	0	0.25	0
	Mud	0.27	0	0.17	0	0.25	0
4. G. atter	Control	0.53	2	0.41	4	0.30	1
	Running water	0.29	0	0.21	0	0.27	0
	Stagnant water	0.24	0	0.25	0	0.25	0
	Mud	0.25	0	0.18	0	0.18	0

Notes: a – Starch contents in percent
b – Powder post beetle attacks in number of holes after 1 year exposed in open
All bamboo samples are about two years old

Table 7. Powder post beetle attacks of stagnant water-immersed bamboo species as Indicator of the first year service life

Felling months	B vulgaris				D. asper				G apus				C atter			
	a_0	a_1	b_0	b_1	a_0	a_1	b_0	b_1	a_0	a_1	b_0	b_1	a_0	a_1	b_0	b_1
May 1980	10	0	49	19	1	0	7	0	0	0	0	0	0	0	2	0
June 1980	5	0	49	0	1	0	12	0	0	0	0	0	0	0	3	0
Jufy I980	5	6	35	8	0	0	0	0	0	0	3	0	0	0	2	0
Aug. 1980	6	0	53	0	0	0	0	0	0	0	0	0	0	0	4	0
Sept. 1980	3	0	45	1	2	0	61	1	0	0	0	0	0	0	1	0
Oct. 1980	8	0	27	0	4	0	12	0	0	0	0	0	0	0	0	0
Nov. 1980	11	0	27	61	1	0	7	1	1	0	2	0	0	0	2	0
Dec. 1980	6	0	63	35	1	0	2	0	0	0	0	0	0	0	0	0
Jan. 1981	4	0	21	24	3	0	17	0	0	0	0	0	1	0	15	0
Feb. 1981	2	0	29	14	3	0	7	4	0	0	0	0	1	0	15	0
Mar.. 1981	3	2	38	20	4	2	44	19	0	0	0	0	0	0	3	0
Apr. 1981	0	0	17	0	0	0	1	0	0	0	0	0	0	0	0	0
Total	63	6	453	182	20	2	170	25	1	0	5	0	2	0	37	0
Average	5.25	0.5	37.75	15.66	1 66	0.16	14.16	2.08	008	0	0.41	0	0 16	0	3 08	0

Powder post beetle attacks on mdividual bamboo species. in number of holes

Notes: % – untreated specimen; b_0 – untreated spectmen

a_1 – 1 month immersion in stagnant water; b_1 1 month tmmerston in stagnant water

Data m a_0 and a_1 are recorded after one month off from the water immerston. whtle b_0 and b_1 after one year off

Conclusion

The Javanese traditional method of bamboo preservation is justified to some extent. The felling season followed is suitable. Immersion in water improves the quality of **Dendrocalamus** asper. Chemical treatment is not economical and beyond the means of the users.

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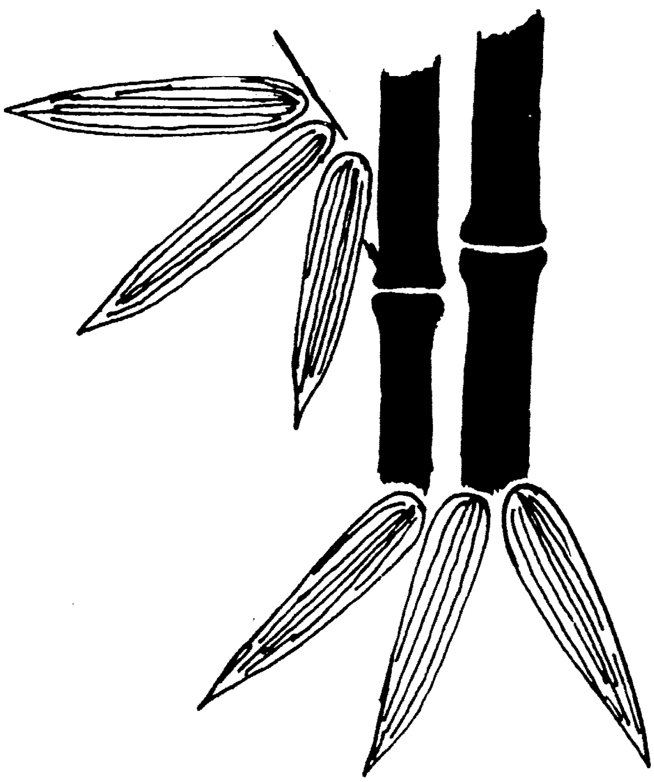

Socio-Economics

Role of Bamboos in Rural Development and Socio-economics: A Case Study in Thailand

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Abstract

Bamboo plays an important role in rurai deoelopment of Thailand. Bamboo shoots provide the rural people with an income in rainy season during which no products are obtained from the major agricultural crops. Bamboo culms are commonly used as construction material of the households in rural area whereas bamboo handicrafts provide an important additional incTTome. The wide uses of bamboos give more employment opportunities and better income distribution. Millions of bamboo culms and thousands of tons of bamboo shoots are haruested annually. The outputs of bamboo utilization from different study sites are presented and the problems of bamboo resource are discussed.

Introduction

Bamboo is the most universally useful plant known to man. For over half the human race, life would be completely different without it. Ubiquitous, it provides food, raw material, shelter, even medicine for the greater part of the world's population (Austin et al. 1983). Bamboos are abundant in Thailand due to its tropical climate. However, the taxonomic studies of bamboo species in Thailand is still in its infancy. 12 genera and 41 species have been described (Smitinand and Ramyarangsi, 1980). Although bamboo has long been recognized as a multipurpose species, very useful in rural areas, it is harvested without any concern for conservation measures and research has been virtually ignored. In the recently formulated Sixth National Economic and Social Development Plan beginning 198'7, bamboo has been selected as one of the species to be developed. This means that the government will have a definite policy on bamboo resources. Bamboo will play a more significant role in rural development, bamboo cultivation will be promoted and more effective uses of bamboo will in turn be expected.

Uses and Applications

The uses of bamboo both in Thailand and elsewhere are so broad and the variety of applications so numerous, only the more important commercial and common types are covered in this discussion. Fig. 1 shows the location of the places referred to in the text.

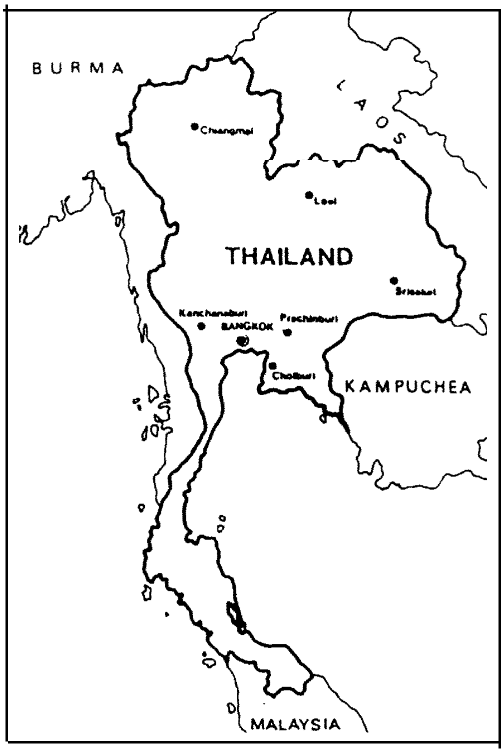

Fig. 1 Location of the study sites.

Bamboo pulp: Bamboo is an excellent resource for pulp and paper making, used in India, Japan and other Asian countries for a long time. Because of its tong fiber, mixing it with other pulp is not necessary and can be used as the sole raw material for making paper. The Kanchanaburi Paper Mill, producing paper from bamboo, was established in 1936 by the Ministry of Industry, and it was a successful operation. But the paper mill had never been a real money earner. The red tape had plagued the operation and, as a result, the mill was closed in September 1984. Although the only mill producing paper from bamboo is no longer under operation, the use of bamboo for this purpose is still going on under the experiment by Phoenix Pulp and Paper Co. Ltd. in Northeast Thailand. There is a potential that bamboo may serve as an important raw material for pulp and paper making at this mill.

Bamboo plywood: Because of its colour and its shiny surface, bamboo has been used as a decorative material for centuries. More recently bamboo has been made into an attractive plywood for buildings. There are two manufacturers of bamboo plywood in Thailand, one in Kanchanaburi and the other in Lampoon (near Chiangmai). Since the production requires quite a lot of raw materials, there are thousands of people engaged in various activities, such as factory workers, bamboo cutters, villagers who weave the bamboo mats. The thickness of bamboo plywood ranges from 1 mm to 10 mm, the size being 120 x 240 cm. The production capacity is about 20,000 boards per month in each factory.

Food: Bamboo shoots are widely used as food in Thailand. The most popular species is Dendrocalamus asper, cultivated commercially in. Prachinburi where 37,975 tons of bamboo shoots were harvested last year. The other varieties are harvested from natural forests throughout the country. Although there is no actual figure of bamboo shoots harvested from natural forests, it can be estimated that some hundred thousands tons of bamboo shoots are harvested annually. Bamboo shoots are preserved in three different ways: dried, steamed, and soured bamboo shoots. The export value of bamboo shoots, mainly in cans, was 80 million Baht in 1984 (US$l = Baht 26.90).

Construction material: In areas where it grows naturally, bamboo is a traditional building material. Houses can be made exclusively from bamboo. Larger culms are used for the piles, stilts and the major framework. Smaller sized pieces are used for floors, windows and door frames. The bamboo can be split into slats for weaving into mat walls. When the culms are split in half and the nodes removed, they can be used interlockingly to form waterproof roofs. The same ingenious application of bamboo is also carried through for furniture, fences, cages, mats, farm implements, ladders, and blinds. Pipes for irrigation and guttering can also be fabricated when the nodes are removed. Bamboo scaffolding is commonly used in building construction since bamboo is extremely resilient and longlasting. Many construction workers also believe that bamboo is safer than rigid tubing. One seldom hears of bamboo scaffolding collapsing even when it is used in multi-storey construction.

A great variety of bamboo handicrafts are made in the rural area throughout the country. They provide the rural people with an additional source of income, Apart from domestic consumption, the 1984 export value of bamboo handicrafts was 70 million Baht. Bamboo handicrafts are also regarded as an old Thai tradition.

Role of Bamboo in Rural Development

Most of the rural people in Thailand are in the agricultural sector, with major crops being rice, corn and cassava. They plant bamboo as a living fence from which bamboo shoot will be used for food and bamboo culm for building material and handicrafts. These people have no income from their agricultural crops during rainy season but they will have bamboo for compensation. The surplus of bamboo shoots can be sold in the local market or preserved by steaming or pickling for future consumption. Bamboo culms can be cut and made into a variety of bamboowares for use in the household as well as for additional income when sold.

For those living close to the forest, bamboo always shares a major part of their houses. It is typical that people in remote rural areas are poor. Their earnings from agricultural crops are not sufficient to cover their yearly expenditure, many of them being heavily in debt. Fortunately, bamboo can relieve such problems. These people will gather bamboo shoots from the forest and sell them to the trader for further processing, The roadside price of fresh bamboo ranges from 1 to 5 Baht per kilogram depending on the time of the year.' One can gather as much as 100 kilograms of bamboo shoots in a day. With a six-month season one can earn quite a lot of money. With such opportunity for earning the poor people in the rural areas will be better off and, as a result, the rural areas are developed both directly and indirectly.

A variety of bamboo handicrafts can be found throughout the country. They represent a unique local tradition which differs from place to place. The rural people in eastern Thailand have the reputation of making very fine bamboo handicrafts while the heavy-duty ones are made in the western region. Many people both Thais and foreigners are astounded to see the very tiny baskets, 1 cm in diameter. In Srisaket and Chiang Mai tourists enjoy their shopping for a great variety of bamboo souvenirs. Bamboo is the most versatile raw material for home industry in the rural area. Bamboo has managed to establish such preeminance because bamboo craftmanship is comparatively simple. While a certain level of competence is necessary, one need not possess a high degree of skill to fashion bamboo into an object that will stand up for practical use. In fact, there have always been a good many people making baskets for their own use. Nowadays, specialist craftsmen are outnumbered by farmers for whom working bamboo is secondary trade. Even school children can make simple bambooware for commercial purpose.

Housing in the rural area needs quite a great quantity of bamboo as construction material, especially for a new settlement in the remote area, using bamboo as a substitute to timber and other material which are scarce and costly. The versatility of barnboo as construction material mentioned in the previous section indicates the great potential role of bamboo in rural community development.

Socio-Economics of Bamboo Production

National bamboo culm production: The quantities of bamboo culms harvested from natural forest and their values from the years 1981 to 1984 are presented in Table 1. The average annual production is 52 million culms are worth 270 million Baht. The figures represent only the output recorded by the Royal Forest Department when bamboo culms are transported through the check points. In fact, a great number of bamboo culms are cut and used in the rural area and are not included in those recorded by the Royal Forest Department. Consequently, the actual figures of culm production may be five to six times greater than those presented in Table 1. The greater part of the culm production is that of Thyrsostachys siamensis and T. oliveri, the rest being Bambusa arundinacea, B. blumeana, B. nana, B. tulda, Dendrocalamus *strictus,* D. hamiltonii, D. membranaceus, Cephalostachyum pergraile, *C. virgatum,* and some other minor species. There is no record of the quantity of bamboo shoots harvested in the whole country. The figure one may get is only the estimate. However, the only records of bamboo shoot production are obtained from bamboo farms and bamboo shoot proceasing factories. It must be kept in mind that such records represent only a small part of the total production.

Table 1. Outputs and value of bamboos harvested from natural forest in Thailand.

Year	output culms	Value Baht'
1981	**63 187 919**	**259 272 947**
1982	**52 981 878**	**344 924 205**
1983	**45 022 244**	**232 827 187**
1984	**48 933 933**	**247 583 463**

'U.S. $1 = Baht 26.90

Source: The Royal Forest Department 1981,1982. 1983. 1984 Annual Reports.

Bamboo in the north: From tourist souvenir to bamboo plywood industry: Thailand's major forest resources are found in the north. This means that the region is very rich in bamboo resource as well. Apart from the uses of bamboo in the households that represent an old culture of this region, bamboo is used to make a variety of products for commercial purposes ranging from tiny items to plywood. There are at least 23 manufacturers of a variety of bamboo products in Chiangmai and its neighbouring town, Lampoon (Table 2). The production capacity can indicate that these manufacturers need a great quantity of bamboo raw material. Bamboo-based industry differs from other industries in a way that more rural people participate in the production process. The bamboo plywood factory in Lampoon is a good example.

The factory produces the standard-sized bamboo plywood, 1.20 x 2.40 m, with different thickness: 1, 2.5,4,6, and 10 mm. The production capacity is 20,000 pieces per month under 60 percent of full capacity. Bamboo plywood is composed of layers of bamboo mats glued and pressed together, Only *Dendrocalamus strictus* and *Cephalostachyum virgatum* are used. The factory provides the members of village farm cooperatives with bamboo raw material. The villagers will split the bamboo into thin strips, weave them into 1.30 x 2.55 m mats before sending them to the factory. The net income of the villagers ranges from 35 to 45 Baht per person per day.

There are about 1,000 families of the rural community who are involved in the production of bamboo piywood. There is a labour shortage in the industry during the rainy season when the members spend most of the time on the paddy fields and other farm lands. Nearly half of the labour force for bamboo mat making is shifted to for cultivation activities. The situation is worse during harvesting period when people earn more money and want to relax from hard work. However, the problem is not as serious as it should be since the factory and the mat makers are dependent on each other. The factory cannot operate without the mats from the rural community, without the factory the members of the cooperatives will have no additional income in order to improve their living condition. Therefore, both sides have to adjust their view to achieve a good cooperation. They are symbiotic.

Tiny bamboo baskets and sweet bamboo shoots in the northeast. The rural people in Srisaket Province have the reputation of making very fine bamboo baskets. Apart from those larger-sized items used in the households, the very tiny baskets, as small as 1 cm in diameter, are made from very fine bamboo slats. These slats are as fine as a thread, therefore skill and patience are required when these slats are woven. The technique has been passed on from generation to generation and it symbolizes the old tradition of the province. The miniature bamboo baskets are made for, commercial purposes as tourist souvenirs, decorative pins in particular.

There are four villages where such bamboo basket making is concentrated. The results of the survey in July 1984 reveal that 53.50 percent of the households in four villages, or 313 out of 585 households, engage in this

Table 2. Bamboo products in Chiangmai and Lampoon Provinces.

Type of products	Number of producers	Production capacity units/month
1. Bamboo plywood	1	20 000 (1.20 X 2.40 m)
2. Trays	3	15 000
3. Handicrafts	9	4 300
4. Souvenirs	3	3 800
5. Jugs	1	3 450
6. Handicrafts for lacquerware making	2	2 000
7. Lanterns	2	1000
8. Sticks	1	7 000 kg.
9. Toothpicks	1	1 000 packs

activity. There is one village in which every household makes the bamboo baskets for commercial purposes. The income from the products for each household ranges from 3,600 to 6,000 Baht per year. This additional income is very important to the rural people, most of whom earn rather little from their main livelihood. There are 24 villages in Loei Province where the people plant the so-called "sweat bamboo". It is called sweet bamboo because the taste of its shoots is not. bitter. The species are Bambusa burmanica and Dendrocalamus whose species is not known to the author. There are 585 farmers who plant these two species on their landlot. The size of the bamboo farm ranges from 0.5 to 10 hectares. However, nearly every household plant sweet bamboo on their home garden, three to five clumps being the most common.

When planted on the farm land, sweet bamboo can produce 1,600 to 2,400 kilograms of shoots per hectare. Each clump in the home garden can produce shoots weighing up to 100-150 kg. The local market price of sweet bamboo shoots is 10 to 15 Baht/kg. This can demonstrate that even the rural people who plant sweet bamboo on their home garden or as a living fence can earn a significant additional income. In the northeastern part of Thailand many people still believe that planting bamboo will bring them death. In the ancient times, bamboo poles were used for carrying coffin. These people would not plant any bamboo since they believe that they would die when the bamboo they planted are big enough to use as carrying poles. This might be one of the reasons why there is very little bamboo resource in the northeast compared with the other regions. This belief is gradually fading out and the people are beginning to plant more bamboos on their land. They have realized how important bamboo can be in their rural development.

Bamboo products: The lifeblood of the rural peoplein Prachinburi: Bamboo is commercially most important in Prachinburi, with many concentrated bamboo farms that support a variety of home industries. The discussion will cover only the utilization of bamboo for commercial purposes. The rural people in Prachinburi usually spend their free time making items from bamboo. Broom making is popular among the young and old people who do not engage in farm work. The broom handle is, of course, bamboo. A skilled person can make as many as 50 to 60 brooms in a day, the profit being 1000 to 1500 Raht per month per person. Since the brooms are used in every house in Thailand there will be a good potential for broom market.

Cephalostachyum pergracile is a typical bamboo for use in hat weaving in one district. The bamboo culm will be split into very thin strips. The strips are woven into bands of 2 cm width, before being sewed into a hat. Three hats can be made from one bamboo internode. The villagerscan make 60 m of bamboo band in a day from which they can earn about 10 Baht per day. Although it is a rather small earning, the rural people can enjoy their additional income.

Bambusa blumeana is used for basket making and mat weaving. This bamboo species is usually planted as a living fence from which the culm, 8 to 10 m long, are obtained and are worth 10 to 12 Baht when sold. The net profit the villagers will get from the baskets and the mats they make is about 15 to 20 Baht per day.

Bamboo furnitures in Prachinburi are made from Bambusa nana and Thyrsostachys ***siamensis.*** The survey for furniture making was made in one village of Prachantakam. There are 213 households in the village, 40 of which are involved in bamboo furniture making. The yearly income for each household is about 16,000 Baht. The production requires 90,000 culms of Bambusa nana nearly all of which are brought from Ubonratchatani and Yasothorn Provinces, 400 to 500 km to the northeast. Faced with the problem of raw material, there is a potential that more Bambusa nana will be planted in Prachinburi in order to avoid material shortage and long distance transport of bamboo culms.

Dendrocalamus asper was brought from China and introduced to the farmers in Prachinburi Province about 80 years ago. This province has since become the most well known centre for bamboo farms. The information about bamboo farms in Prachinburi is presented in Table 3. The f.o.b. price of the fresh bamboo shoots ranges from 2 to 8 Baht per kilogram depending on the time of the year. Nearly all of the bamboo shoots harvested from

Table 3. Shout production from *Dendrocalamus asper* plantations in Prachinburi Province in 1984.

District	Planting area ha	Productive area ha	output tons/ ha	Total output tons	Number of factories
Muang	2 368	2 0 %	11.250	23 580	17
Prachantakam	480	400	10.625	4250	2
Kabinburi	458	256	9.375	2400	2
Nadee	409	320	10.625	3400	1
Srakaew	640	400	9.375	3 750	–
Srimahapote	56	32	10.000	320	–
Aranyapratet	46	24	8.750	210	–
Kokpeep	8	8	8.125	65	–
Total	4 465	3536	–	37 975	22

the farm are sold to canning factories. Steamed bamboo shoots in cans serve both domestic and foreign markets. The number of canning factories can very well guarantee the future of bamboo farms.

The art of bamboo handicrafts in Cholburi Province: A very fine bamboo handicraft can be found in Panatnikom District of Cholburi Province. Cephalostachyum pergracile is widely used not only for handicraft but also for other purposes. The market price of one internode about l m long, is 5 Baht. There are four bamboo culm dealers in Panatnikom who sell about 12,000 internodes per month. The nodes can be used as fuel which is also sold at 10 Baht per sack or 0.5 Baht per kilogram. Ten baskets. 12 inches in diameter, can be made from the strips of three internodes. The villagers receive 17 Baht for one basket. It is very promising work for the rural people who invest 15 Baht for three bamboo internodes to get 170 Baht for ten baskets made. However, it must be kept in mind that this does not happen every day since people cannot devote much of their time for such work.

A special survey was made at the Handicraft Cooperatives of one village in PanatnikOm. The cooperatives were founded in 1976 in order to organize the activities of the members for better quality of products. better marketing, and more benefits. Before the cooperatives were founded, the income from bamboo handicrafts was 400 to 600 Baht per household per month. Such income was raised to 900-1,200 Baht per month during the first six years of the cooperatives. The income has been 1,300 to 1,600 Baht per month since 1982, higher income being expected during the years to come.

Kanchanaburi: The centre of bamboo utilization: The most concentrated area of bamboo growth in Thailand is in Kanchanaburi area, 130 km west of Bangkok. Logically, Kanchanaburi is the centre of bamboo utilization in Thailand. It is worth mentioning that Kanchanaburi is the only province in Thailand where 12 species of bamboo are legitimately controlled species. These species are Thyrsostachys siamensis, T. oliveri, Arundinaria pusila, A. ciliata, Bambusa arundinacea, B. blumeana, Cephalostachyum pergracile, GigantochIoa albociliata, Melocalamus compactiflorus, Melocanna humilis, Schizostachyum aciculare and Teinostachyum griffithii.

21.95 million culms were harvested from natural forest in 1982, 22.45 million culms in 1983 and 14.96 million culms in 1984. These bamboos were used in different kinds of industries both in Kanchanaburi and neighbouring provinces.

A special survey was made for the amount of bamboo shoots harvested from the forest. It is impossible to ger the real figure. but the data from some specific study sites will reveal the concentration of bamboo shoot utilization. The data was gathered from

Table 4. Production of sour sliced bamboo shoots in Thongpapoom, Kanchanaburi Province.

Producer No.	Number of working days	Workers		Production kg
		Number	Monthly wage Baht/person	
1	120.	25	800	294 700
2	120	15	1 100	195 000
3	120	4	900	62 500
4	90	5	1 200	125 000
5	60	5	1000	45 000
6	60	8	800	36 000
Total	–	62	–	758 200

those who make sour sliced bamboo shoot in Thongpapoom, the district next to the Burmese border. The information about sour sliced bamboo shoot making is presented in Table 4. These producers employ only 62 workers, whose working period ranges from 60 to 120 days in a year. Occasionally. other people are also involved. They are the bamboo shoot cutters who sell bamboo shoots on roadside for 2 Baht per kilogram on average; the shoots are those of Bambusa *arundinacea, Dendrocalamus brandisi* and D. strictus. The quantity of sour sliced bamboo shoots made in this district can demonstrate how the' income is distributed to the rural people. There is one bamboo canning factory in the city of Kanchanaburi that produces steamed bamboo shoots for export to Japan. The production capacity is about 350-400 tons per year. Thyrsostachys *siamensis* and *T. oliveri* are the only species to be used. Kanchanaburi is and will continue to be the centre of bamboo utilization in Thailand. This means that the rural people in this region can still enjoy using this precious gift of nature.

Conclusion

The uses of bamboo have long been very well known to man. Since bamboo is ubiquitous, people always harvest bamboo without any conservation measures. The natural bamboo resource will diminish in relation to the depletion of forest area. The scarcity of bamboo resource in the future will force people to plant more bamboos for use in their households and sell the surplus, if any, for additional income.

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Genetic Diversity and Socio-Economic Importance of Bamboos in India

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Abstract

India has the richest diversity of bamboos and the total annual production is one of the highest in the world. Distribution of bamboos in the country, socio-economic role of bamboos, conservation of gene pool and plant imprvoement are discussed.

Introduction

The bamboo is an important economic plant intimately associated with mankind since ancient times. It is a natural gift to the people in areas where it is abundant. It provides the basic necessities of life i.e. food, shelter and clothing. Besides these, it also provides raw material for cottage and paper industry. Thus it provides livelihood for millions of people. It is no more a poor man's timber as it serves both the poor and the rich with its numerous useful products. It is a renewable source of energy in the form of fuel for the rural population.

Bamboo is a fast growing grass with woody habit. It is widely distributed all over the world. Sharma (1980) has reported about 75 genera and 1250 species distributed in different parts of the world, mostly confined to South-east Asia. India has a rich diversity of bamboo genetic resources. Bahadur & Jain (1983) reported 113 species of bamboo belonging to 22 genera whereas Sharma (1980) reported nearly 136 species of bamboos occuring in India. The notable among these are Bambusa arundinacea and Dendrocalamus strictus. Although bamboo occurs in tropical, subtropical and temperate zones, it prefers humid and warm climate for best growth.

India has perhaps the world's richest resources of bamboos, with almost 50% of the species present in north-eastern region. Bamboos occupy about 9.57 million hectares of forest area, which constitute about 12.8% of total land area under forests (Vermah and Bahadur, 1980). The estimated annual production of dried bamboos is 3.23 million tonnes which is about one fifth of total wood production of the country (Vermah and Bahadur, 1980). It is reported that about 2 million tons of bamboo is consumed every year by the paper and rayon industries in India (Subha Rao. 1966).

Distribution of Bamboos

Out of 22 genera in India, 19 are indigenous and 3 exotic, introduced for cultivation. The indigenous genera are: ***Arundinaria, Bambusa, Cephalostachyum, Chimonobambusa, Dendrocalamus, Dinochloa, Gigantochloa, Indocalamus. Melocanna. Neohuzeoua, Ochlandra. Oxytenanthera, Phyllostachys, Pseudostachyum, Schizostachyum. Semiarundinaria, Sinobambusa Teinostachyum,*** and ***Thamnocalamus.***

Other genera like Guadua, Pseudosasa and Thyrsostachys – are occasionally cultivated. Vermah and Bahadur (1980) reported the bamboo distribution in India as follows: ·

In India, as elsewhere, bamboos form rich belts of vegetation in moist deciduous, and semi-evergreen tropical and subtropical forests. Very few species occur in the Himalayas of north-western India. The states particularly rich in bamboos are Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram. Nagaland. Sikkim. Tripura and

West Bengal. Bamboos are also rich in Andamans. Baster region of Madhya Pradesh. hills of Uttar Pradesh. Bihar. Orissa and Western Ghats.

Flowering in bamboos is rare and erratic. In some species it takes place after 3-4 years, in others they flower once in 30 or 40 years, once in a life cycle. Cultivation of bamboos is done by seeds or offsets or by other vegetative methods of propagation. Plant height varies from small to very tall. Yield of bamboo varies from 2.5 to 4.0 tonnes per hectare, depending upon the intensity of planting, stocking and varieties available. A felling cycle of 3 or 4 years is normally adopted.

	Region	Number of Genera	Number of Species	Genus (Species)
1.	North-eastern India	16	58	Arundinaria (9), Bambusa (12). Cephalostachyum (5). Chimonobambusa (6). Dendrocalamus (7). Dinochloa (2). Gigantochloa (2). Melocanna (1). Neohouzeaua (2). *Oxytenanthera* (2), *Phyllostachys* (2). Pseudostachyum (1). Semiarundinaria (1). Sinobambusa (I), Teinostachyum (1), *Thamnocolamus* (4).
2.	North-western India	5	14	Bambusa (4). Chimonobambusa (2). Dendrocalamus (4), *Phyllostachys* (2), *Thamnocalamus* (2)
3.	Indo-Gangetic Plains	4	8	*Bambusa* (4), *Cephalostachyum* (1). *Dendrocalamus* (2). *Oxytenanthera* (1).
4.	Peninsular/South India (Eastern & Western Ghats)	8	24	*Bambusa* (3). *Cephalostachyum* (l), *Chimonobambusa* (l), *Dendrocalamus* (1). *Indocalamus* (3). *Ochlandra* (9). *Oxytenanthera* (5). *Teinostachyum* (1).
5.	Andaman	6	7	*Bambusa* (2). Cephalostachyum (I), *Dendrocalamus* (1). Dinochloa (1). Oxytenanthera (l), *Schizostachyum* (1).

Socio-economic Role of Bamboos

Bamboos occupy a very important place in the economy of the countries in which it is commonly available and in abundance. Every part of the bamboo is utilized in one way or another. It is one of the most useful indigenous natural resource in India. Out of nearly 10 million tonnes of bamboo (annual world production), about 3.5 million tonnes are produced in China (Sharma. 1980) and 3.23 million tonnes in India (Vermah and Bahadur. 1980). It provides raw material for cottage industry and employment for millions. It is estimated that harvesting of bamboos in India itself requires about 71.25 million man days every year (Vermah and Pant. 1981).

Bamboo has been utilized for paper for a long time, but- its utilization for large scale manufacture of paper is very recent. Nearly 80 paper-mills are dependent wholly or partly on bamboos in India. as they provide long-fibred resource easily available at cheap prices (Sharma. 1980). 'in Asia, India is the largest consumer of bamboos for the manufacture of paper. Most of the paper mills have been established in the region of large scale bamboo growing areas. Approximately 2 million tonnes of bamboo are at present being utilized for paper in India. and this leads to a production of nearly 600.000 tonnes of paper-pulp every year (Vermah and Bahadur. 1980). There are many advantages of using bamboo for making paper-pulp as compared to other resources. Bamboo being very fast growing, without bark. long-fibred. cheaply available. supports paper industry with raw material for the manufacture of newsprint. quality paper and card-board paper.

Commercial exploitation and Bamboo improvement

Out of more than 100 species of bamboo growing in India, only about ten species are commercially exploited. A few other species are utilized to a limited extent in cottage industry. Some of the economic bamboo species are: Bambusa arundinacea. B. balcoa. B. polymorpha. B. tulda, B. vulgaris, Dendrocalamus brencisii, D. hamiltonii, D. strictus, Ochlandra scriptorea and 0. travancorica (Haque 1984). Bamboos are being utilized in a number of ways. The quality of its fast regeneration, strong. straight, smooth, light and hard wood. easy transportation. splitting. cutting and its glossy surface make it suitable for making a large number of products for daily use. The commonly used articles are mats. basketeries, ropes, beds, brooms, bridges, umbrella handles, pipes, fans, brushes, nails, anchors, fishing rods, furniture poles, agricultural implements, ladder and others. The present revenue derived from bamboo is estimated at about Rs. 66.77 million per year which can be further increased by encouraging bamboo industry (Vermah and Bahadur, 1980).

Inspite of modernisation in industry, demand for bamboos is increasing, There has been constant efforts to increase cultivation area to meet the demands. Nearly 160,000 hectares of new land has been brought under bamboo cultivation in different states of India. Recently bamboos are used as water pipes in Bihar state (Vermah and Pant, 1981). Bamboos are extensively used in building construction. Recent research at F.R.I. Dehradun has successfully used ,it as a reinforcing material, replacing steel in various cement concrete construction, such as roof shed, beams, electric posts etc.

Use of bamboo shoots as pickles, in chutneys etc has been increasing. Some species have very succulent shoots which are highly nutritious and palatable. These are consumed in a variety of ways. Cultivation of edible bamboos can increase foreign exchange and therefore bamboo-shoot farms are important. Leaves of some species form good fodder, especially for elephants. In some species, there is a bitter element – hydrocyanic acid present in the leaves, poisonous to' the animals. Bamboo seeds are used as food grains at the times of famine.

Living bamboos provide good fencing along farm houses, gardens and bungalows serving as ornamentais as well. Some of the dwarf types of bamboos are used as ornamental plants in trays and pots.

Bamboos are also used in the pharmaceutical industry. Extraction of an important drug – Taibashir from the dry-cuims of some species of bamboos is well known. The sugar silica from the cuims is used as a cooling tonic and an aphrodisiac.

Rhizomes of bamboo species are cut into small pieces for use as buttons. Bamboos are also grown for afforestation of denuded lands to check soil erosion. It is a fast growing source of fuel wood for the rural people. Bamboo charcoal is preferred in gold-smithy.

In India, there is an urgent need to check devastation and protect natural vegetation of bamboos and to increase bamboo cultivation for meeting the increasing demand. There is a lot of scope in the export of bamboo handicrafts. Bamboo plantations raised solely for pulp and paper would not be profitable, as the royalty generally paid by the mills is very low as compared to the cost of raising the plantation, but bamboo raised for cottage industry pays good profit as they are sold by the number of culms. Therefore when the bamboo plantation is raised for pulp and paper, some of the plants should be earmarked solely for the cottage industry. Some subsidy should also be paid to farmers cultivating bamboo for commercial purposes. According' to one estimate, bamboo consumption in India for;, housing construction is about 16%, for rural uses about 30% and the rest are for paper-pulp and other uses (Sharma, 1980). For increasing bamboo cultivation, the crop should be included under the social-forestry programme.

Since vast genetic diversity of bamboos is available in India, there is an urgent need to conserve different species available. Forest Research Institute, Dehradun (India) has maintained the richest collection of bamboo germplasm at present. It has conserved more than 35 species of bamboos in several arboreta and are being used for taxonomic studies, breeding for improved types, timber-engineering, pulp and paper technology, silviculture and tissue culture for quick multiplication. Research on physiology of flowering in bamboos is also in progress at various universities in India.

Recently, bamboo has been included as one of the multi-crop programme for study. under "All India Coordinated Research Project on Under-utilized and Under-exploited Plants", scheme approved by Indian Council of Agricultural Research (ICAR) with headquarters at National Bureau of Plant Genetic Resources, New Delhi and research centre for bamboos at I.C.A.R. Research Complex for North-Eastern Hills is at Basar in Arundachal Pradesh (India). Activities on survey of bamboo genetic resources in north-eastern region, and their collection have been initiated from 1984-85. Germplasm of bamboos will be collected, evaluated and conserved at the centre.

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Economics for Bamboo Forestry Research: Some Suggested Approaches

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Abstract

Bamboo is a commodity of historic economic value in Asia, Within the context of a steadily declining total natural forest stock in Asia, bamboo is becoming an increasingly scarce resource. Public and private *initiatives to reverse this trend, should consider bamboo cultivation as a viable alternative benejitting people* both *in* public *(social) and private (market) lands. Bamboo research and subsequent , development programmes should include economic analysis as an integral component for developing appropriate technology and in investing* resources for *employing that technology. Specific techniques of economic analysis; i.e. benefit-cost analysis, marginal analysis, budgetting* and *market research; are suggested vis-a-vis specific bamboo research and development objectives. Foresters are encouraged to involve experienced micro-economists in their research and/or undertake specialized* short-term relevant micro-economics *training.*

Introduction

From the information provided at the 1980 Workshop on 'Bamboo Research in Asia' (Lessard and Chouinard, 1980), and in other publications (Austin *et al.,* 1983); it is obvious that in Asia, bamboo is ecologically, socially and commercially an important plant. From, this same literature, plus the results of recent research as presented in this workshop; it is equally obvious that there exists a potential to significantly increase the production of bamboo .and improve its productivity in present and alternative uses, In other words, bamboo has 'value'. It is seen as a relatively scarce resource (due to low productivity of natural stands) with many uses in manufacturing, as a food and in making paper. Its collection and/or cultivation, processing and consumption involve people from different socio-economic groups in society. With new technology in such areas as — controlled flowering, seed technology, tissue culture, insect control, preservation, etc; it will be possible to increase extensive and intensive production and improve processing, employing many more physical and human resources of land, labour and capital.

By definition, economics is a study of the proper method of allocating scarce resources among competing uses (Ferguson, 1972). It attempts to answer the three basic questions of (Sammedson and Scott, 1968) 1. What to produce? — what mix of different outputs? 2. How to produce? — what techniques should be used to produce output? 3. For whom to produce. — who should receive the output produced? These are relevant questions with respect to scientific research and national development activities on bamboo to improve people's lives.

This paper is a limited attempt to provide a rationale for economic analysis of new technology for bamboo production and preservation. The arguments for conducting economic analysis, and the suggestions for using specific techniques, draws heavily from the work in Farming Systems Research (FSR) (Banta, 1982 Anon, 1984 Anon and Department of Agriculture Nepal, 1980), and Post-Harverst Research (PH) Austin, 1981; Edwardson and MacCormac, 1984) in Asia,

Bamboo as a Natural Forest Resource

Historially, in countries (or regions within a country) with a very low population density, the forest was considered a "common property natural resource". No single user had exclusive rights to the forest nor could he prevent others from sharing in its exploitation. As long as the annual 'cut' or harvest from the forest was less than or equal to the annual net natural growth of the 'stock' of the forest, people's needs were assured. There was no incentive to control or limit access to the forest. This situation no longer exists for Asia today. Since the end of World War ll, rapidly increasing population, with associated demands for fuel and farm land, and the fact that the developed country wood demand outpaces supply; has resulted in a significant decrease in land under forest in Asia. Between 1960-80, one-half of the increase in food supply in Southeast Asia came at the cost of extending crop areas in forests' (Barney, 1980).

The remaining forest areas are generally, in principle, subject to laws regulating their use. However, the effectiveness of these laws are limit&d due to needs of shifting cultivation, the needs for fuel which can be obtained without cash by rural (and urban) people, and the ability of special interests to disregard the laws without penalty. What this means is that traditional 'natural' forest stands cannot maintain or increase supplies of wood. While information on individual species is often difficult to obtain, it is reasonable to assume that the forest stock of bamboo and the total annual net growth has and will continue to decrease significantly under present conditions in Asia. Increasing forest (including bamboo) output over time by extending the area under cutting is no longer a long-term option. The raw material for an expanding wood products (including bamboo) demand will be found by intensifying production (Scott, 1982), (perhaps with the exception of Indonesia).

The Potential for Economic Intensive Bamboo Cultivation

Scott (1982) and Sedjo (1982) discuss the potential for intensive forest production in Asia. While they focus mainly on monocyclic and polycyclic timber (plantation) systems, several relevant points are made which are important regarding the economic feasibility of bamboo cultivation. Both polycyclic and monocyclic systems produce significantly higher mean annual increments (MAI) than natural forests, The extra costs of physical and management inputs should be offset from direct increased production, and there are other indirect national benefits in increased employment for production and wood processing. Bamboo has a rapid natural early growth which can be increased with application of fertilizers, Traditional techniques and 'industrial infrastructure' for processing bamboo exists, therefore expanding production should be quickly followed by an expanding processing sector, provided a market exists for the extra production.

The shorter the forest species rotation cycle, the less time this 'capital' (growing stock) has to be held before disposal. Related to this is that the longer the rotation cycle, the longer input costs are compounded and the longer future benefits must be discounted back to the present. Bamboo's very short rotational cycle makes it very attractive in terms of cash flow vis-a-vis other hardwoods and softwoods. This makes it attractive for those with little capital. The comparative net benefit over time would of course depend on factors such as the relative magnitude of costs and expected future prices of the species.

Monocyclic plantation systems require large areas and present evidence suggests that relative to polycyclic systems; they present a greater environmental threat due to a lack of flora-fauna mix and by sudden extensive destabilization of water flows by the disturbance of moisture absorbing watersheds. Bamboo seems well suited to poiycyclic harvesting, can be grown on steep hillsides and along banks of rivers, its interlocking root system and leaf deposit inhibit soil erosion (Austin, 1983). In Asia, countries have. little high quality arable land left for expanding crop area. Efficiency in the use of water and maintaining soil quality in even marginal agricultural areas, have both direct and indirect benefits to food producers and consumers.

Related to some of the above arguments is the issue (mentioned earlier) of the competitiveness of forestry versus agriculture. As Asian countries move closer to the 'cleared-forest' society, the success of forestry will depend upon its relative (to farming and urbanization) costs and benefits. Bamboo, either as a plantation or integrated into a farming system as a crop has potential, for many of the reasons stated earlier. However, it is important to note that in such a situation, the decision to maintain a forest crop (as bamboo) becomes highly decentralized. Region or site specific factors of environment, market demands, relative resource costs and product prices, etc will be the key determinants. A second characteristic is that the decisions become more micro-economic rather than socio-political (unless the government is willing to incur costs in the form of subsidies or transfer payments for a perceived social benefit). This means that local communities or associations and individual farm households will also decide if bamboo should be cultivated. This also means bamboo must be economic (per unit land area) not just compared to other tree species but compared to agricultural crops too. Or at least, it must complement crop production without reducing farm household income. It would appear that bamboo does have significant potential for economic intensive culture. Scientific research to produce the necessary technology must be accompanied by economic analysis to evaluate the ability of that technology to achieve private and social development goals.

Suggested Economic Analysis Approaches

This section is not a detailed "how to" manual for conducting economic analysis for specific bamboo forestry problems. That would require a lengthy presentation complete with detailed examples and take several days to present. Instead, some specific economic analysis approaches are listed followed by specific bamboo forestry research and/or development objectives, to which the economic approaches could be applied. It is understood that bamboo research and/or development projects can have more than one objective. How this is handled usually depends on the specific situation, Usually, secondary objectives. are expressed as constraints for selecting techniques to achieve the main objective (Gregersen and Contreras, 1979) (i.e. increasing bamboo output for paper making is the main objective but environmental objectives help determine harvesting techniques). It is up to researchers to be aware of the social and private decision makers' objectives and the relative weighting they give to those objectives, in the design and evaluation of new bamboo production and processing technology.

Benefit-Cost Analysis

Economic (Social): This form of economic analysis has been widely used in the natural resources to help assess the economic efficiency, from society's point of view, of new technology. It attempts to identify and quantify costs and benefits to society (not just individuals) by utilizing resources over a specified time period. It is not dependent only on known market prices for inputs and outputs but estimates values for such things as increased or decreased soil erosion, reduced unemployment, improved foreign exchange earnings, and other public "bads and goods". In the case of bamboo, this type of analysis can, for example, be used where the objective of research is to – develop and implement techniques for environmental soil and water conservation, soil improvement, shelterbelts, and increase the area under forest. The costs and benefits of those objectives are not only shared or consumed by specific individuals but by 'society' or groups within society. This analysis calculates the "net benefit" or "return" to society employing alternative bamboo techniques.

Financial (Private): This form of analysis calculates the costs and benefits to identified individuals and organizations using market prices only. The same methodology of discounted (over time) cash flow is used as in Economic Benefit-Cost Analysis, however the focus is on calculating the net benefit and return to the actual equity capital invested in the new technology. In the case of bamboo, this type of analysis can, for example, be used where the objective of research is to – maximize economic'output per unit time for a variety of market uses, i.e. paper-making, furniture, food; minimize costs of production and processing for a given quantity of bamboo cultivated or processed; and to develop economical techniques for improved quality of bamboo and bamboo products.

In both forms of Benefit-Cost Analysis, there are three main criteria by which a single or set of techniques can be assessed and compared. These are: (i) Benefit-Cost ratio: This is simply the total of the present worth of expected benefits divided by the total of the present worth of expected costs. Only technologies with a ratio of greater than 1 are economically efficient in terms of resource use. (ii) Net Present ***Worth*** (sometimes referred to as net present value): This is the difference between the present worth of the expected benefits less the present worth of the expected costs. All technologies which result in a positive net present worth are economically efficient in terms of resource use. (iii) Internal Rate of Return: This is defined as the average earning power of the value of resources used from the application of the technology. Only technologies that give a rate of return higher than the existing market interest rate are resource efficient.

The formal mathematical statements of these criteria are given below (Gittinger, 1976) :

$$\text{Benefit-cost ratio} = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+i)^t}}$$

$$\text{Net present worth} = \sum_{t=1}^{n} \frac{Bt - Ct}{(1+i)^t}$$

Internal rate of return is that discount rate i such that

$$\sum_{t=1}^{n} \frac{Bt - Ct}{(1+i)^t} - 0$$

where,

Bt = benefits in each year.

ct = costs in each year.

t = 1, 2 ,........ n.

n = number of years.

i = interest (discount) rate.

It should be noted that in comparing alternative (bamboo) technologies if due to resource constraints, only one of the alternatives can be employed, a comparison of the net present worths of the alternatives is the appropriate selection criteria.

The Single Variable Input-Output Production Relatioship .

Consider a product Y (bamboo, in kg), whose yield depends only on one input X (fertilizer, in kg) assuming all other inputs are used at a constant level. Where a unit of fertilizer is added, total output increases by some amount. Extra output resulting from 1 kg increase in fertilizer is called the marginal product of fertilizer (MPx). When multiplied by the price per kilogram of bamboo, we obtain a monetary measure called the marginal value product (MVPx) . The MVP represents the value of extra bamboo resulting from the application of an additional kilogram of fertilizer. On the cost side, the addition of a kilogram of fertilizer increases costs by a certain amount. This is called the marginal factor cost (MFC). It is equal to the price of the fertilizer, since increasing the use of fertilizer by one unit increases cost by an amount equal to the price of the fertilizer. Hence, using the rule stated above, the use of fertilizer should be increased as long as its MVP is greater than its MFC. To identify the optimum level of fertilizer, that is, the level where profits are maximized, we need to observe how production responds to fertilizer application. Assume that the output-input relationships are as shown in columns 1 and 2 in Table 1.

These show that when fertilizer (x) is increased, bamboo yield (Y) generally increases. At Iow fertilizer levels, the increase in yield from each 10 kg of fertilizer used is large. However, the yield increases from each unit of input (10 kg fertilizer) become smaller at successively higher levels of the input. In other words, extra yield (marginal product) tends to decrease at successively higher fertilizer levels if all other inputs are held constant. This observation is usually referred to as the law of diminishing marginal returns and applies to all input-output situations. In Table 1, percentage of yield increase begins to decrease when more than 30 kg of fertilizer is applied. This reflects the law of diminishing returns. Total yield begins to decrease when more than 100 kg of fertilizer is applied, but this decrease in total yield is not a necessary condition of the law of diminishing returns.

Column 3 of Table 1 shows the marginal product as fertilizer is increased in 10 kg units.

Table 1. Illustration of a simple input-output relationship.

Fertilizer (kg)	Yield (kg)	Marginal Product (kg)	Value of extra output (M)'	cost of extra input (M)
0	2000	–	–	
10	2100	100	110.00	40
20	2300	200	220.00	40
30	2600	300	330.00	40
40	2800	200	220.00	40
50	2900	100	110.00	40
60	2950	.50	55.00	40
70	2980	30	33.00	40
80	3000	20	22.00	40
90	3010	10	11.00	40
100	3010	0	0	40
110	3000	-1	-11.00	40

' M is used as monetary unit.

At fertilizer levels above 30 kg, yield increases but marginal product decreases. We say diminishing returns has set in at 30 kg fertilizer. Assuming bamboo price is 1.10/kg, column 4 shows the value of extra output, or the marginal value product (MVP), which is obtained by multiplying MP by the unit price of bamboo. MVP equals the additional value of output resulting from each 10-kg increase in fertilizer. Column 5 shows the cost of extra input or the marginal factor cost (MFC), which equals the increased cost of each additional IO-kg bag of fertilizer. If fertilizer price is 4/kg, a 10-kg increase in fertilizer will raise cost by 40. Therefore, marginal factor cost equals 40 because we are dealing with 10-kg bags of fertilizer,

Using this information, we can determine the quantity of fertilizer that will maximize profits by following the rule that additional fertilizer should be applied as long as extra return (MVP) is greater than extra cost (MFC). It is sufficient to compare columns 4 and 5. We can see it pays to increase fertilizer use up to 60 kg because value of additional output (MVP) is greater than additional fertilizer cost at levels lower than 60 kg.

Does it pay to increase the fertilizer level up to 70 kg? The larger value of the bamboo obtained from using more fertilizer is 33. Additional cost is 40. The farmer would be losing 7. Clearly, this will mean a reduction in net profit. Hence, he should stop at 60 kg where profit maximization occurs. To confirm that profit is maximized at 60 kg of fertilizer, compute total profit at each fertilizer level. This is illustrated in Table 2.

Columns 1 and 2 are the same figures as in Table 1. Column 3 is obtained by multiplying yield by the bamboo price (1.10/kg). Column 4 is obtained by multiplying the amount of fertilizer applied by its price per kg (4/kg). Column 5 shows net return, which equals value of production less total cost.

Note that profit increases as fertilizer is increased from 0 to 60 kg. Maximum profit is obtained at 60 kg fertilizer. Beyond 60 kg, net return decreases. Note also that maximum yield (at 90-100 kg fertilizer) does not mean maximum profit.

Although this illustration is simple, it provides a guideline for determining maximum profit level of input use. We compare the marginal value product with the marginal factor cost. This analysis shows information on marginal productivity of an input can be expressed in monetary terms and compared with the input price. When $MVPx>Px$, less input is being used than would maximize profits. When $MVPx<Px$, too much input x is being used. Because the law of diminishing returns generally holds for all input-output relations, the profit maximizing level of any input will be less than the yield maximizing level. Note that yield was highest at 90 kg fertilizer but profits were highest at 60 kg fertilizer.

Table 2. Illustration of how to compute total profits.

Fertilizer (kg) 1	Bamboo (kg) 2	Total Value of production[a] 3	Total Cost of fertilizer[b] 4	Net returns[c] 5
0	2000	2200	0	2200
	2100	2310	40	2270
[illegible]	2300	2530	80	2450
30	2600	2860	120	2740
40	2800	3080	160	2920
50	2900	3190	200	2990
60	2950	3245	240	3005
70	2980	3278	280	2998
80	3000	3300	320	2980
90	3010	3311	360	2951
100	3010	3311	400	2911
110	3000	3300	440	2860

[a]Column 2 x 1.10. [b]Column 1 x 4. [c]Column 3 less 4

Budgets

Budgets are one of the simplest yet most widely used techniques in economic analyses. Budgets are used: i) to compare economic profitability of · different technologies; ii) to indicate whether a proposed change (i.e. new technology) will be profitable under a given set of circumstances; and iii) to explore conditions under which certain technologies become profitable or unprofitable.

Enterprise budgets, partial budgets, and parametric budgets are the three common types.

(i) Enterprise budgets: The process of producing a particular commodity is called enterprise. Small farms in tropical Asia usually are multi-enterprise farms — they produce more than one commodity possibly including bamboo. Enterprise budgets enable us to evaluate costs and returns of production processes. Comparing relative profitability of new technology with existing technology helps to show how the enterprise can be more profitable. The new technology may change existing technology to show a better way to grow bamboo or to compare possible new cropping patterns including bamboo.

A budget is a formalized way to compare production process benefits and costs. If benefits exceed costs, profit was earned. If benefits are fess than costs, a loss was incurred. The difference between gross returns and variable costs is called the gross margin (also referred to as returns above variable costs). Gross margin measures the contribution of an activity to profitability. Input quantities and values used in production process (costs) and output quantities and values (benefits) are the basic data required for budgets.

(ii) Partial budgets: Partial budgets are used to evaluate the effects of a proposed enterprise change. A partial budget is useful only when the change is relatively small. A partial budget highlights variations in costs and returns caused by proposed changes in the enterprise. Only items affected by the change are included in the budget. Levels and costs of all unchanged inputs are not included. When constructing a partial budget identify: costs that will increase or decrease, and returns that will increase or decrease.

Table 3 shows a basic partial budget. The left side shows negative effects of a proposed change — added costs and reduced returns of changing from an old to a new technology. On the right side are the positive effects — added returns and reduced costs. If positive effects exceed negative effects, proposed practice is more profitable than the existing production practice.

(iii) *Parametric budgets:* For any new technology, estimates of inputs and outputs are approximate, and prices are subject to change. Therefore, it is useful to explore how sensitive benefits are to changes in assumed levels of inputs, outputs, and prices. We often want to learn what yields and/or prices are necessary to make a technical change profit-

Table 3. Partial budget to estimate change in annual net cash income resulting from some change in resource use.

a. Added costs	c. Added returns M
b. Reduced returns	d. Reduced costs M-
Subtotal A:M	Subtotal B:M
	Estimated change (B-A)M

able. Parametric budgets, also called sensitivity analyses, answer these questions. The simplest situation to consider is the change in profit if one parameter is varied. Gross margin is then calculated as:

$$GM = (PXY) - VC$$

where

GM = total gross margin
Y = bamboo yield
(the factor to be varied)
P = the price of bamboo, and
VC = total variable cost.

Gross margin can now be calculated for any yield within the range that yields are expected to vary. Table 4 presents gross margin for a range of yields between zero and 4,000 kg/ha. The data are also plotted in Figure 1. The figure shows that a yield of less than 1,198 kg is a loss for the enterprise. This yield is usually called break-even yield, calculated by solving for Y when (PY) - VC = 0. It is where the producer just recovers variable costs.

Market Research

Market research is an important type of economic research with respect to the development and recommendation of new technologies for growing and/or processing bamboo. For a,government or private institution (or private individual) to invest in new bamboo technology, it is essential to have data on input markets (resources used in bamboo production or processing) and output markets. The main marketing aspects to be considered in a market study are (Ranaweera, 1984): (i) input supplies, (ii) expected output increases, (iii) market potential (demand), (iv) capacity of the marketing system to handle increased output, and (v) anticipated government interventions.

Table 4. Effect of changes in yield on gross margin . .

Yield (kg/ha)	Gross margin (kg/ ha)
0	-1258
1000	208
2000	842
3000	1892
4000	2492

‘GM = (Y x 1.05) - 1258.

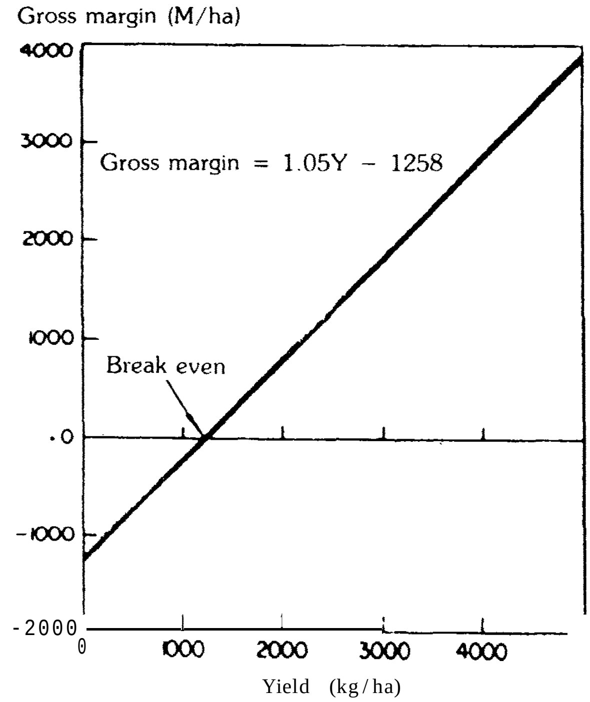

Fig. 1. Effects of changes in yield levels in gross margin.

Conclusions

This paper has had two objectives. First, define a role for economic analysis as part of a total research effort to develop new technologies for bamboo cultivation and utilization, and second, suggest specific economic analysis procedures that could be used. The material presented for the second objective is very superficial, in that the reader is strongly recommended to consult the references cited for developing even a basic understanding of the related economic concepts and techniques. It is also recommended that agricultural or resource economists with experience in micro-economic analysis be encouraged to undertake this research. Much of this analysis could be done by foresters if they have received appropriate training (a minimum of 6-8 weeks) from economists. The decisions to include an economist and/or train foresters in basic micro-economics for this research should depend on: (i) how 'basic' or 'applied' the bamboo research is, (ii) the existing availability of interested and/or experienced economists, and (iii) the research and training resources available.

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Reports on Sessions

Reports on Technical Sessions

Technical Session.1

Chairman: **Prof. Mu Zhowg Lun**
Rapporteur: **Prof. A. N. Rao**

In the technical session I on Monday, 7 October 1985 six papers were presentd during the morning and afternoon sessions.

1. In the first paper presented by Mr Sharma, the general importance of bamboos in the *Asia Pacific region* was stressed. The present status of bamboo production and use in India, Bangladesh, Thailand, Malaysia, Philippines, Indonesia, Papua New Guinea, Sri Lanka, Burma, Korea, Japan and China was briefly reviewed. The assessment for the total bamboo resources is available only for some of the Asian countries, especially those where bamboo is used as raw material for paper industries. The importance of a good assessment for each country was emphasised especially where bamboo is an important component of the cottage and rural industries. Both the research output and the improvement of cultivation techniques are important to increase the bamboo resources and altogether about 12 suggestions are offered. The paper was well received and during discussion particular points regarding gregarious flowering habit, hormonal and water relationships, utilisation of abandoned land, suitability of bamboos to be used as water pipes, salt tolerant varieties and the other related aspects were covered.

Professor Wu Bo presented his paper on 'The present condition of bamboo research and production in *China*' and reviewed the development of bamboo industry in his country. For most of the audience this was an excellent introduction to the status of bamboo research undertaken in China and the high quality bamboo production in enormous quantities.

In the next paper presented by Dr Salleh Mohd. the bamboo resources in *Malaysia* was reviewed with plans and strategies for further development. In view of the other forest resources available in great abundance due emphasis is not given so far for bamboos. The annual production of bamboos for the whole country is not estimated, though figures for certain states like Kedah, are available. Several cottage industries in the country using bamboo as basic material are adequately sustained. Regarding the development strategies enough technology should develop to improve the bamboo based, rurally centred smafl scale industries and the techniques for harnessing and managing the raw materials should improve. After presentation there was some useful discussion on the virtue of selective cutting, usefulness of aerial surveys and proper methods for the administration of bamboo projects and other related aspects.

Bamboo in *Indonesia* — a country report was the next paper presented by Dr Haryanto. The cultivation of bamboo is an ancient art in Indonesia and along with banana as well as coconut (popularly known as BBC), they provide both food and building materials for the rural population. The small holdings around villages Pekarangans are millions in number covering about 31,700 ha as against 50,000 ha of bamboo land as part of the natural forests. Research on cultivation and utilisation is carried out in universities and research institutes and further progress is necessary to meet the demand of the people in the 21st century. Many questions were asked about the selective harvesting, curing and treating of bamboos.

Professor Lantican was the next in presenting the paper on 'Bamboo production and utilisation research in *Philippines*'. Bamboos are extensively used in Philippines in the fishing, banana and furniture industries. The handicraft and furniture industry, based on bamboo resources brings considerable foreign exchange. Other uses of bamboo in building construction, for flooring, pulp and paper industry were explained. Research needs to improve the production and utilisation of different species were outlined and the research priorities were listed. After the paper presentation there was some discussion on the rate of bamboo production/given land area and the dissemination of information on bamboos in the region.

The next paper was the 'country report — Sri Lanka' by Dr Vivekanandan. Bamboos are mostly used for rural housing. Of the seven genera and 21 species present in the country only Dendrocalamus strictus has been planted on a large scale, The progress of research work done in the previous year as a part of the IDRC project was outlined which concerns about the stem propagation methods in *Bambusa vulgaris.* Other conditions suitable or large scale propagation were explained and discussed. After the presentation there was discussion on the suitable method of planting and the effects of hormone treatment to improve the growth of the propagules .

As the last paper of the session I, Dr Boa presented a brief report on 'Bamboos in Bangladesh as the other invited members from Bangladesh could not attend the seminar. There is a total area of 54,000 ha of bamboo forest in the country in addition to bamboos grown in and around the villages. Recently an inventory was prepared for the whole country and the cultivation of bamboo is increasing. However, there is very little space available for bamboos growing and due to water logging bamboos die in certain areas. Forest bamboos are thin and mostly used for paper. Both overcutting and extraction are the real problems. Many improvements to remedy the situation were suggested.

After the presentation of all the papers the rapporteur summarised the main points that emerged from the presentation of papers and the discussion followed, which included the following:

1. There should be some standardisation in the recognition of the various species.

2. A good network for the exchange of information on bamboos is urgently required.

3. The cost of production and the relative effectiveness of different methods presently followed should be carefully studied since the bamboo resources are fast disappearing in many countries.

4. There is an urgent need for extra propagation material in every country to use bamboos as soil binders and to prevent soil erosion.

5. Destruction of bamboos for better land use is a myth since most of them grow only on marginal soils.

6. Greater attention should be paid to recognise genetic variability available within the species to select better varieties for cultivation. Many of the taxonomic problems need to be solved to eliminate duplication of species and to establish the new ones, if need be.

At the very end of the session a request was made to all the authors to submit the original copies of their papers including graphs, figures, diagrams etc. Wherever necessary each paper will be discussed with the individual authors to make the necessary amendments and to establish proper format for publication of the proceedings,

Technical Session II

Chairman: **Prof Geng Bojie**
Rapporteur: **Prof Y M L Sharma**

Six papers were presented during the session.

In the paper presented, Mr Stapleton, (Nepal) spelt out the efforts initiated by him on vegetative propagation techniques in barnboo (few important species) for evolving an efficient and appropriate technology to suite the topographic, climatic and biotic factors prevailing in Nepal. His paper stressed on the efforts to induce quick rooting of bamboo species to achieve maximum percentage of success in the field.

In an interesting and illustrated paper, Mr Hansken of Panda Products, USA, detailed the efforts made to propagate Phyllostachys ***pubescens,*** and raise seedlings for supply to the people. It is a very enterprising venture aimed at propagating Phyllostachys ***pubescens,*** and reminds of some private farmers in Tamil Nadu of India raising seedlings for supply to cultivators for raising bamboos in the agricultural sector.

Mr Fu Maoyi in his paper highlighted the benefits of the application of fertilisers to raise the bamboo crops including the methods of application, dosages and the result of application of such fertilisers. It has been reported that the fertiliser application helps greatly the growth of bamboos. In fact the current trend is the use of more and more of fertiliser in forestry crops.

In her well presented paper, Miss Chen Fangne highlighted the hybridisation work on bamboos carried out in China. She has also highlighted the characters of pollen of bamboos and other features like the period of seed ripening, stressing the importance of the viability of pollen as the key factor in the success of these hybridisation work.

Presenting his paper, Dr Eric Boa detailed the different pests and diseases of Bamboo in Bangladesh. The culm sheath regions were reported to be the vulnerable places of infection. He has also cautioned about the drawbacks in raising large scale monoculture of bamboos.

In his second paper, Dr Eric Boa highlighted the incidence of bamboo blight disease in some parts of Bangladesh, especially in the village bamboos. He stressed the need for a more intensive study of the subject, and to determine the predisposing factors. It was also suggested by the Rapporteur the possibility of growing bamboos in mixtures with tree crops, and the need to prevent the spread of the disease across the borders of Bangladesh.

Technical Session III

Chairman : Prof Hsiung Wen-yue
***Rapporteur:* Dr Salleh Nor**

Three papers were presented in this session.

According to Dr Anan Anantachote, bamboo is a very important resource in Thailand, but it is decreasing in quantity; the silvics unknown. Thus, his study focussed on the basic flowering characteristics of economic bamboos in Thailand. High variability in seed germination percentage, the correlation between moisture content and presence of seed borne fungi are important. During discussion, clarifications were sought on actual seed M.C., which is the air dry M.C. and on the seed borne fungi which has not been used for inoculation tests yet. On the question of physiological changes before flowering, Dr Anan replied that when clumps do not produce new shoots, it is likely that they will flower the next dry season.

Dr Usui of Japan discussed in detail the studies on morphology of a number of Japanese bamboos. Morphological studies must be supported by other basic research in anatomy and taxonomy. On a question whether branching of bamboo is regulated by arrangement of prophylls in a bud, it was left unanswered.

In his presentation, Prof Rao, Singapore, focussed on the growth, anatomy, taxonomy, cytology and reproduction of certain bamboos in Singapore. Following there was a second presentation on the preliminary work on tissue culture of certain bamboos.

Details on tissue culture of bamboos created some interest with questions on the explants used for the experiments and the meristemable tissues.

Technical Session IV

***Chairman:* Dr Walter Liese**
***Rapporteur:* Dr Celso Lantican**

Ten papers were presented in this session.

The paper on Anatomy and Properties of Bamboo was presented by Dr Walter Liese. With the aid of slides, Dr Liese gave a comprehensive account of the present state of knowledge about the anatomical, chemical, physical and mechanical properties of bamboos. For many of the properties, he indicated that variations exist along the height and across the wall of a culm.

During discussion the following questions were raised.

1. Is penetration of preservatives possible through the stomata of the center walls?

   Preservatives enter by diffusion. There are no stomata on the walls.

2. You mentioned that bamboo shrinks even when it is still green. Can you tell us what the fiber saturation point of bamboo is?

   This is a subject that still needs to be investigated.

3. When is a culm mature and why does a culm senesce?

   Little research has been done on anatomical changes as the culm gets older. The work of Dr Chen at Nanjing has shown that there is a dramatic and puzzling increase in the elements of older culms. We do not know why a culm senesces and why it becomes brittle and loses its strength.

The next paper was by Dr Higuchi on Characterisation of Steam-exploded Bamboos for Cattle Feed. The paper, presented with slides, described the use of the steam explosion process to convert bamboo chips into a form that can be hydrolysed by cellulose. According to the author, the process is promising for the production of cattle feed and obtaining the material for fermentation.

Questions were raised during discussion:

In Germany, it has been observed that in cattle dungs the parenchyma cells bearing the warty layer are not digested. What is your finding on EXB's?

Ruminants cannot digest the ceils if they are covered with lignin. EXB's are devoid of lignin as this is separated in the process.

The paper on Anatomy and Properties of Bamboo by Dr Janssen dealt with the structure, properties and advantages of bamboo as the building material. The information given centered on mechanical properties that are useful for designing bamboo structures.

In the next paper, Mr Li showed that strong bamboo structures, much bigger in area and taller than ordinary houses, can be successfully built as has been done in Switzerland.

The discussion followed the presentation.

How do you put the base of the culm on the ground?

It is erected on a concrete foundation with a steel plate bolted.

What material was used to tie the culms together for the columns of the building?

Bamboo skin strips and steel strips.

I am of the opinion that construction with bamboos require a lot of skill, which is absent in Malaysia. Are there any schools or courses dealing with construction of bamboo structures in China?

Yes, some schools have. (Note: Some participants offered the information that some publications dealing with the subject are available).

Did you have to secure permits and insurance for the bamboo building you put up in Switzerland?

These were arranged by the Swiss government.

Mr Achmad Sulthoni presented the paper on Traditional Preservation of Bamboo in Java. The results of a study involving the use of certain traditional methods of improving the service life of bamboo were outlined. It was concluded that the existing practices regarding the time of cutting and water immersion has scientific basis and therefore the methods outlined are recommended.

The following questions were raised.

Did you try to relate the biological life cycle of beetles with the occurrence of beetle attack?

I studied the beetles involved but was not able to correlate the life cycle changes and the occurrence of the attacks.

The loss of starch in culms soaked in water is it caused by bacterial action rather than by leaching?

I believe it is due to bacteria because starch is not soluble in water.

Mr J N Lipangile presented the paper on Use of Bamboo as Water Pipes.

This paper discussed the engineering characteristics, preservation, construction methodology, maintenance, and economics of bamboo used as water pipes. The paper reported, that bamboo pipes are four times cheaper than locally purchased plastic pipes of the same diameter.

Mr Slob presented his paper on CCA Impregnation of Bamboo.

The paper presented the results of the study in which CCA was impregnated into bamboo pipes of the species Arundinaria *alpina* using the Boucherie process. High leaching rates of the toxic compounds were observed; hence, it was concluded that CCA-treated bamboo is not appropriate for use as water pipes.

Dr Liese and Dr Higuchi advised the Tanzanian delegates (Lipangile and Slob) to "be very careful" in using preservatives on water pipes as they can endanger human lives and pollute the environment,

Role of Bamboo in Rural Development and Socio-economics: A Case Study for Thailand was presented by Mr Songkram Thammincha. The use of bamboo in the national economy and on the improvement of the quality of life of the rural poor was outlined. A cost-benefit analysis of bamboo farming was presented. Destruction of bamboo in some parts of Thailand is rampant. Efforts should be made to stop this. It was also suggested that shoot management be studied to ensure sustained yield.

Socio-economic Role of Bamboo in India and Their Genetic Diversity was presented by

T A Thomas. The paper indicated the species present in the country, their distribution and socio-economic role. It pointed out the high genetic diversity of bamboo in the country where 22 genera and more than 136 species are present. It also indicated that bamboo research on collection and conservation is being carried out at FRI, Dehra Dun.

Economics for Forestry Research: Some Suggested Approaches was presented by C W MacCormac. This paper suggested specific techniques of economic analysis VIS-A-VIS specific bamboo research and development objectives. The discussion included the following.

1. in conducting a benefit-cost analysis, how do you measure the intangibles?

   This is a very important issue. There are no rules available. My suggestion is that the scientist should work with an economist in the estimation of values.

2. Which is more economical, shoot production or culm production?

   Research on this is needed.

Concluding Remarks from the Chairman

The Chairman commended the speakers, the discussion leaders and the rapporteurs, as well as the interpreters for doing their jobs well.

Research Needs and Priorities

Introduction

The information, ideas and concepts enumerated in the following paragraphs are a summary of the final session of the workshop. There was recognition among participants that the present workshop was taking place after a period of five years, since the first one held in Singapore in May 1980. Though considerable effort had gone into activating the research agenda that was identified in 1980 much needed to be done if the bamboo culture, cultivation and utilization is to contribute meaningfully to the economies and peoples of the region.

Information

The major difference between what was documented in Singapore and the present one was the expression for a bamboo information centre or service. The bamboo community, be it research, commercial or consumer has been growing at a rapid rate. The present flow of information was inadequate to the needs of the community and therefore an urgent need existed for the establishment of an information collecting and disseminating facility to serve Asia in the first instance and the rest of the world subsequently.

Conservation

Fears were expressed at the erosion of the genetic pool not only because of excessive exploitation especially in the S. Asian region but also because of the extensive habitat destruction in the S. E. Asia region. It is therefore highly desirable that urgent steps be taken to collect all of the germplasm available in each region for conservation purposes in situ (through bamboo gardens) or ex situ in special ecological reserves.

Taxonomy

The classification, nomenclature and identification of bamboos still continues to vbe a major problem in South and S. E. Asia. On going research work has to be enhanced to expedite studies in other areas like breeding especially for increasing yield, disease and pest resistence etc. The need for an Asian bamboo taxonomic monograph still exists and some initiative should be taken immediately to produce this.

Silviculture

Much is known about the ecology and silviculture of bamboos in some countries while in others little information is available. Especially in the case of the latter, where sympodial bamboos are concerned, research needs were expressed for the following studies:

- The phenological characteristics of all commercially important species. Information was especially needed on factors inducing or inhibiting flowering behaviour; the ageing of bamboo, physiological mechanisms of shooting, etc.
- The root characteristics of the principal sympodial species.
- Appropriate propagation and nursery technologies to assure large and continuous supply of seedlings.
- Suitable plantation technologies for establishing industrial scale plantations and the risks associated with monocultural situations.
- Options for establishing multicropping systems with bamboo as one of the components.
- Options for using bamboo to rehabilitate devastated lands, control of canal and river banks,
- The types, level and methods of application of fertilizers, associated economics as well as growth studies in man made plantations.

- Pest and disease situation among bamboo stands.

Management and Harvesting

The science of managing bamboos is new to a number of countries and specific prescriptions will have to be worked out for each environment. The following studies were considered important on the basis of traditional presumption that bamboos have to be worked through culm selection:

- cultural operations to bamboo stands from the time of formation
- clump and culm spacing
- moisture retention techniques
- felling intensities and methods of felling
- fabrication of improved tools for cutting, splitting and binding bamboos.

Utilization

The forum reiterated the need to continue research on the topics identified by the 1980 workshop, as progress has not been as rapid as expected. Further some of the following studies were suggested for inclusion in the agenda:

- A detailed study on the variability being encountered in terms of durability within species.
- A closer study on the correlations between species' properties and traditional utilization.
- The functions of the various tissues and cells (eg. parenchyma, phloem, nodes) and their impact on preservation, seasoning etc.

  The quality of the culm with reference to their maturation and/or senescence.
- The chemistry of bamboo and its subsequent application in chemical utilization (manufacture of plastics, membranes, conversion to fodder, pulping etc) .

Socio-economic studies

The forum expressed a need to undertake cost-benefit studies on bamboo cultivation given the fact that land is a scarce resource in the region and the promotion of bamboo forestry should be seen in the context of other crops.

Further, data has also to be gathered on the social value of bamboo especially as a feature of water and soil conservation.

Education and Extension

Unanimously it was pointed out that bamboo serves multiple uses and therefore in parts of the Asia Pacific region where bamboo has not been recognized for its potential in improving rural incomes a concerted effort should be made through the use of demonstration, plantations, training rural social workers with multi-media materials and organizing formal courses within a forestry curriculum.

G. Dhanarajan

International, Bamboo Workshop (China)
October 6-14, 1985
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Post Script

We have spent considerable time and effort in editing the proceedings solving many of the problems and difficulties connected therewith. These were mostly concerned in editing the manuscripts. reducing their length. wherever necessary or even rewriting some of them which were Gi very poor quality to begin with either in terms of language, expressron or accuracy of facts or all of them. We were completely familiar and anticipated the various problems before we started the work. Some of them could be solved by ourselves, whereas in case of others the manuscripts had to be returned to the authors to implement the necessary correcttons or changes and to provide proper explanations and/or illustrations Obviously all these exchanges delayed the publication We appreciate the patience and endurance of other authors who would have liked to see or receive the publication much earlier.

The papers included in this proceedings contribute a wealth of information on bamboos that would help the researchers and the students who are studying the various aspects of these interesting plants. We hope that this volume like its predecessor will also serve as an useful source of reference for many years to come.

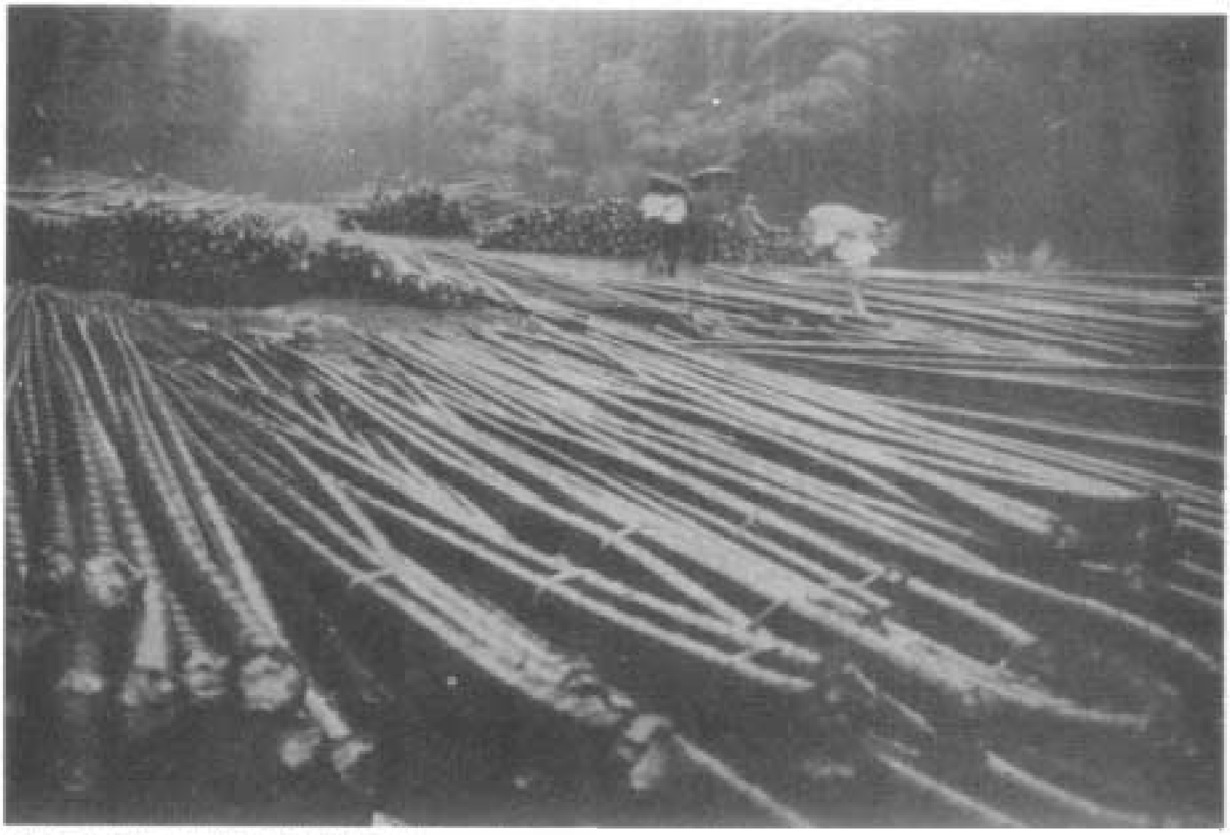
We are indebted to Mr Kevin Tan for his enormous patience and cooperation in rescheduling the printing programme of this volume many times. Equally grateful we are to many of our colleagues who helped us in many matters. in one way or the other.

– Editors

The gateway — that all entered and came out happily with more ideas.


The person who answered all questions — almost all, the problem solver, Mr Fu.

Bamboo Road to success.



After harvest ready for shipment

Participants in the plantation-discussing the rate of growth.

Expriment in progress.

The Workshop Participants