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Editors:
Gilles Lessard and
Amy Chouinard

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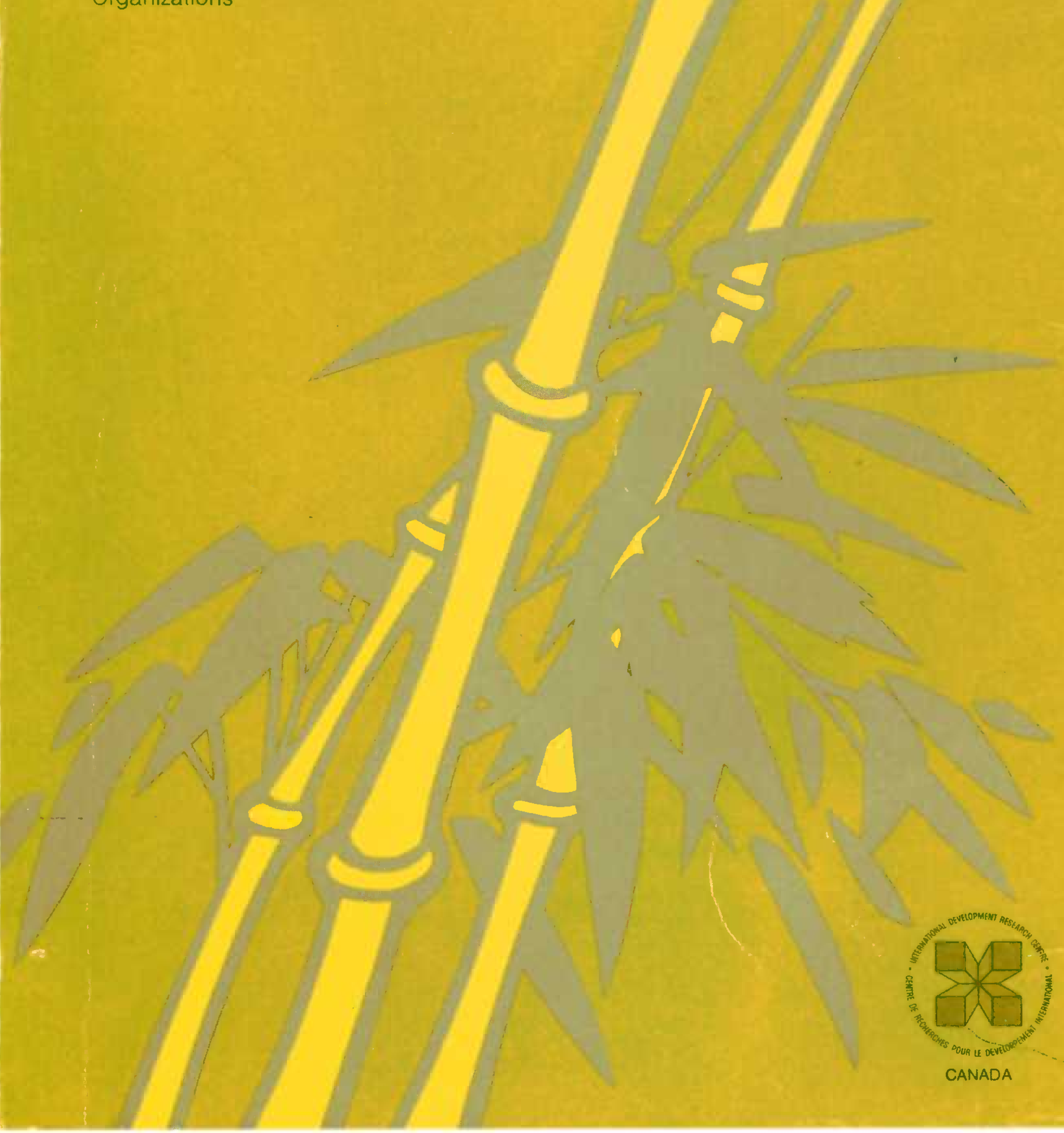
Bamboo Research in Asia



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

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Bamboo Research in Asia

Proceedings of a workshop held in Singapore, 28–30 May 1980

Editors: Gilles Lessard and Amy Chouinard

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Contents

Anatomy of Bamboo

W. Liese[1]

A brief description of the anatomical structure of the bamboo culm is presented as a basis for an understanding of the physical properties of bamboo. I looked closely at the parenchyma and vascular bundles and sorted out the correlation between several bamboo species and certain types of vascular bundles. I also examined the fibres in the internodes, reporting the average lengths of fibres found in some species of bamboo.

The properties of the bamboo culm are determined by its anatomical structure. The bamboos, belonging to the Gramineae, possess a primary shoot without secondary growth. The culm consists of internodes and nodes. In the internodes the cells are axially oriented, whereas the nodes provide the transversal interconnections. No radial cell elements, such as rays, exist in the internodes. The outermost part of the culm is formed by a single layer of epidermal cells, and the inner side is covered by a layer of sclerenchyma cells. Therefore, lateral movement of liquids is minimal, and the pathways for penetration of liquids are limited to the cross ends of a culm and — to a much smaller extent — the leaves at the nodes.

The gross anatomical structure of a transverse section of any internode is determined by the vascular bundles, their shape, size, arrangement, and number. The vascular bundles contrast the parenchymatous ground tissue, which is much lighter in colour. At the peripheral zone of the culm, the vascular bundles are small and numerous; at the inner part, larger and fewer. Within the culm, the total number of vascular bundles decreases from bottom to top, and their denseness increases correspondingly.

The culm consists of parenchyma cells forming the ground tissue and the vascular bundles composed of vessels, sieve tubes with companion cells, and fibres. The total culm consists of about 50% parenchyma, 40% fibres, and 10% conducting cells (vessels and sieve tubes). The percentage distribution shows a definite pattern within the culm, both horizontally and vertically. Parenchyma and conducting cells are more frequent in the inner third of the wall, whereas in the outer third the percentage of fibres is higher. In the vertical direction the amount of fibres increases from bottom to top, with the parenchyma content decreasing. The common practice of leaving the upper part of a cut culm unused in the forest is therefore a waste with regard to its higher cellulose content. The distribution of cell types within the culm is influenced by the type of vascular bundle present.

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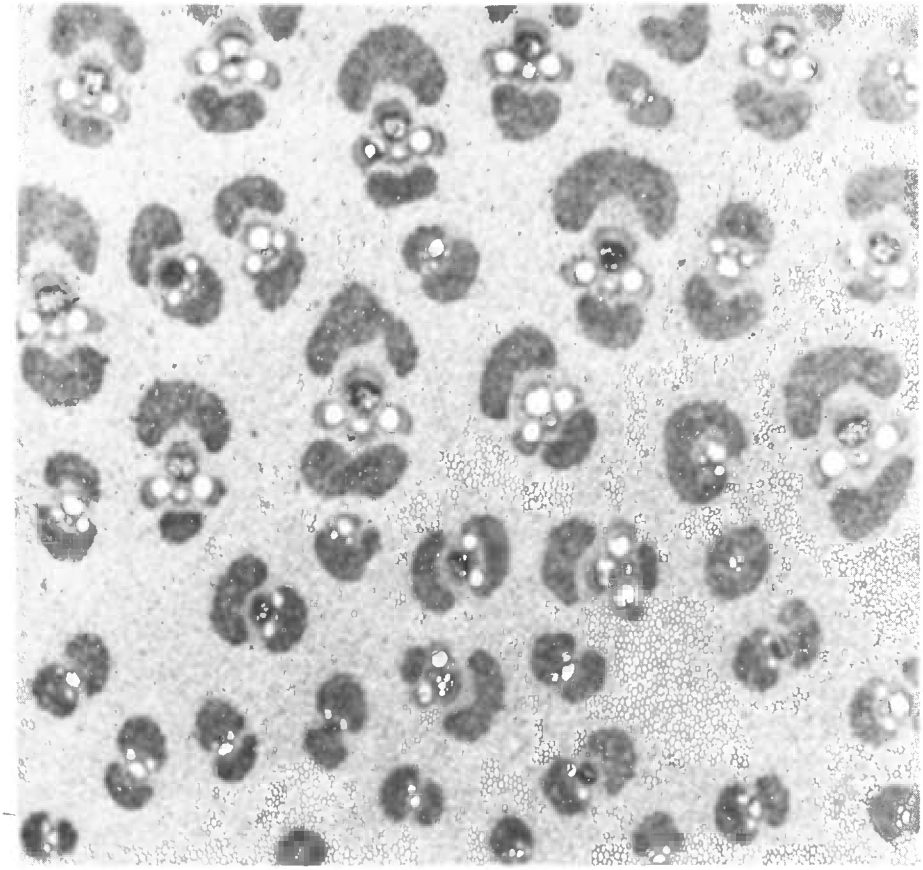

Bamboo vascular bundle type IV.

Parenchyma

The ground tissue consists of parenchyma cells, which are mostly vertically elongated (100 × 20 μm) with short, cube-like ones interspersed in between. The elongated cells possess thicker walls, which become lignified in the early stages of shoot growth. The shorter cells are characterized by a denser cytoplasm and thin walls; the walls do not show lignification even in mature culms and retain their cytoplasmic activity for a long time — a fact that is demonstrated by the presence of peroxidase. The function of these two different types of parenchyma cells is still unknown. It may be investigated in relation to the unsolved mystery of the maturing process of a bamboo culm and its longevity. The relative high values of cold- and hot-water extractives of up to 10% are due to the large amount of parenchyma. The parenchyma cells are connected with each other by small, simple pits located on the longitudinal walls.

Vascular Bundles

The vascular bundle in the bamboo culm consists of xylem with two large metaxylem vessels (40–120 μm) with one or two protoxylem elements and the phloem with thin-walled, unlignified sieve tubes connected with companion cells. The vessels are larger at the inner part of the culm and become small toward the outer part. This conducting tissue functions throughout the lifetime of a culm without addition of any new conducting tissue in contrast to hardwoods and softwoods with their cambial activity. In older culms, vessels and sieve tubes can become impermeable due to depositions of gum-like substances. Also, blocking of sieve tubes by tylosoid-like outgrowths occurs.

Both the vessels and the phloem are surrounded by sclerenchyma sheaths. They differ considerably in size, shape, and location, according to their position in the culm and the bamboo species. Most of the species have separate fibre strands on the inner or the inner and outer side of the vascular bundle. Intensive studies have led to the differentiation of four types of vascular bundles:

- Type I consists of the central vascular strand; supporting tissue only as sclerenchyma sheaths;
- Type II consists of the central vascular strand; supporting tissue only as sclerenchyma sheaths but the ones at the intercellular space strikingly larger than the other three;
- Type III consists of the central vascular strand with sclerenchyma sheaths and one isolated fibre bundle; and
- Type IV consists of the central vascular strand with small sclerenchyma sheaths and two isolated fibre bundles on opposite sides.

The presence of these vascular-bundle types in the bamboo species and their distribution within the culm correlate with the taxonomic classification system of Holttum based on the ovary structure. For example, type I alone is found in *Arundinaria* and *Phyllostachys;* type II alone, in *Cephalostachyum;* types II and III are found in *Melocanna* and *Schizostachyum*; type III alone is found in *Oxytenanthera*; and types III and IV are found in *Bambusa, Dendrocalamus,* and *Gigantochloa.*

The leptomorph genera (nonclump-forming) have only the vascular bundle type I, whereas the pachymorph genera (clump-forming) possess types II, III, and IV. Size and shape of the vascular bundles vary across an internode but also with the height of a culm. They become smaller from bottom to top. Within the nodes, an intensive branching of the vessels occurs with special analogical structures by which the passage of (invaded) air is prevented. Vessels run also through the nodal diaphragms so that all sides of the culm are connected at the nodes.

Fibres

The fibres in the internodes occur as caps of the vascular bundles and in some species additionally as isolated strands. They constitute 40–50% of the total tissue. The fibres are long and taper toward the ends. Their ratio of length to width varies between 150:1 and 250:1. The length shows considerable variations both between species and within one species. The average fibre length of some species has been determined; for *Bambusa arundinacea,* it is 2.7 mm; *B. textilis,* 3.0 mm; *B. tulda,* 3.0 mm; *B. vulgaris,* 2.3 mm; *Dendrocalamus giganteus,* 3.2 mm; *D. membranaceus,* 4.3 mm; *D. strictus,* 2.4 mm; *Gigantochloa aspera,* 3.8 mm; *Melocanna baccifera,* 2.7 mm; *Oxytenanthera nigrociliata,* 3.6 mm; *Phyllostachys edulis,* 1.5 mm; *P. makinoi,* 2.5 mm; *P. pubescens,* 1.3 mm; *Teinostachyum* sp., 3.6 mm; and *Thyrsostachys siamensis,* 2.3 mm.

Various values have been reported for one and the same species. The reason is mainly that there is considerable difference of fibre length within one culm. Across the wall, the fibre length often increases from the periphery, reaches its maximum at about the middle, and decreases toward the inner part. Or the length may exhibit a general decrease from the outer part to the inside. The fibres at the inner zone of a culm are always much shorter (20–40%). An even greater variation (more than 100%) exists longitudinally within one internode. The shortest fibres are always near the nodes, the longest in the middle part. With increasing height of the culm, a slight reduction in fibre length occurs. Any measurement of fibre length has therefore to allow for this pattern of variation within the culm and should be based on representative samples.

The anatomical structure of most fibres is characterized by thick lamellated secondary walls. This lamellation consists of alternating broad and narrow lamellae with differing fibrillar orientation. In the broad lamellae, the microfibrils are oriented at a small angle to the fibre axis, but the narrow ones are mostly horizontally oriented. The narrow lamellae exhibit a higher lignin content than do the broader ones. A typical tertiary wall is not present, but in some taxa warts cover the innermost layer. Some species possess regular septate fibres, in which a horizontal lignified and lamellated wall (septum) divides the fibre lumen into chambers. The polylamellate wall structure of the fibres, especially at the periphery of the culm, leads to an extremely high tensile strength as demonstrated in the engineering constructions with bamboo culms.