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BIOLOGICAL ASPECTS OF BAMBOO AND RATTAN FOR QUALITY IMPROVEMENT BY POLYMER IMPREGNATION*

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The treatment of timber with monomers for the production of lignomers with improved technological properties and biological resistance has been investigated in detail. Attempts are now being made, to apply the procedure also to bamboo and rattan in order to produce value-added products. The efficiency of monomer penetration depends on the anatomical structure of the material to be treated. The structural parameters of bamboo and rattan in comparison with wood are elaborated. Practical consequences regarding the modification of bamboo and rattan by monomer impregnation are outlined.

INTRODUCTION

This lecture is given in the memory of Professor Dr. Tadeusz Perkitny, the senior of wood research at the Agricultural University Poznań, who passed away on August 8, 1986 at the age of 84 years after a long and successful life for wood science. Among the various lines of work Professor Perkitny was concerned with the upgrading of wood quality by technological processess. The prospects of wood improvement have been further developed and extended by his successor, Prof. Dr. Ławniczak. Since 1977 scientific symposia deal every second year with the many facets of wood modification. The most recent one, the 9th in September 1993, has covered a wide range of topics for the quality improvement of timber in Europe.

However, the chances of technological developments have to be considered and applied not only for timber, but also for other biological materials which have economic importance in other parts of the world. Much concern exists about the destruction of the tropical forests, about the decreasing availability of timber in these regions and about the lack of employment in rural areas.

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One of the consequences is a greater consciousness of renewable local resources, which are plentiful and utilized since ever. I may stress especially for bamboo and rattan as two major biological assets, which give hundreds of millions of people material, shelter, housing, food and employment. Thus, already Professor Perkitny praised the comfort of his bamboo home during his stay in Laos [20]. The general appreciation of rattan furniture in Poland was demonstrated by at least five companies at the Furniture Fair, April 2 1994, in Poznań. The wider and wiser utilization of these often neglected natural goods is the target of quite a number of international, national, institutional and also commercial activities. To mention especially are the International Development Research Center (IDRC) and its offspring, the International Network for Bamboo and Rattan (INBAR), the IUFRO Project Group P5-04 and projects in Costa Rica and on Bali.

Since about 15 years nearly countless investigations have dealt with the properties and improved utilization of bamboo and rattan. Both materials are used for a wide range of commodities, but as a disadvantage both have a low natural resistance against biological deterioration. Since they do not develop "heartwood", a chemical preservation is often considered as the only solution for increasing their service life. Also, certain species of bamboo and rattan are classified as inferior material, either due to cracking, swelling or breaking or, because of their lower technological properties.

Among the many investigations carried out for improving their behaviour, only a few have considered so far the possibilities of polymer impregnation with the aim to increase technological properties and durability against deterioration by organisms. Due to the increasing environmental concern about the use of toxicants for the protection of timber and bamboo and the awareness about the safe disposal of treated residues all possibilities for nontoxic treatments are to be considered.

Investigations in Taiwan have dealt with the manufacture of bamboo-plastic combinations with a thermo-plastic monomer [5] and with the resistance of bamboo-polymer composites against insects attack [4]. Also rattan has been a material for related studies, as investigations with phenolic resin impregnation [26] have shown. These efforts are now extended to lesser popular palms, in order to produce value-added products. Also the stem of oil palm, considered for a long time as a waste after the rotation-time for harvesting the seed bunches, is subject for improvement by polymer impregnation [25].

Such innovative approaches are not confined to the bamboo and rattan growing countries, since Prof. Ławniczak has contributed by applying the experience and technology developed in Poznań, to the needs of bamboo improvement. Thus, a paper was delivered at the 4th International Bamboo Workshop 1991 in Chiangmai, Thailand on "Bamboo-Polymer composite-new construction material" [14] and two further ones at the recent 1st National Bamboo Convention, November 1993, in Bandung, Indonesia on "Method of production and properties of the composite bamboo-polystyrene elaborated in Poland" [15, 18]. Also the possibility for cocos wood polymer composites have been studied in Poznań [17]. These contributions originated from our mutual exchange of ideas in the respected fields of interest. Investigations on the impregnation of bamboo and rattan tend to apply an established technology with known monomers on the lesser well known material bamboo and rattan. Both have a quite different structure from timber, experimented with so far. The anatomical make-up of these monocotyledons bears principle dissimilarities compared with timber, which influence much the results of a treatment and the expected quality of the products. Generally, any liquid penetration into timber, into bamboo or rattan depends on suitable anatomical pathways. The considerable influence of the completely different structure of monocotyledons on monomer impregnation has not been outlined so far. The purpose of this treatise is therefore to present the structural parameters of bamboo and rattan for the penetration of monomers. On this basis prospects and also limitations can be evaluated and possible fialds of application identified.

BASIC CONSIDERATIONS FOR THE POLYMER IMPREGNATION OF WOODY MATERIAL

Numerous investigations have delt with the production of wood polymer composites [13, 21, 22]. The results have shown that:

– Monomers do penetrate through the lumina of the cells and through openings in the connecting pits, but much less through pit membranes.

– Infiltration of the cell wall is limited to only few substances with low molecular weight.

– Material to be treated must be air-dry, so that no liquid water hinders the flow of the monomer. The presence of water inhibits the polymerization of some monomers.

– To overcome the structural barriers and the hindrance by compressed air due to the invading monomer an evaporation of the woody material is necessary, followed by a pressure-forced penetration, thus requiring a substantial technical instrumentarium.

For the impregnation of timber it is well established, that great differences exist in the penetration of the monomers according to the species, thus only permeable species can be succesfully treated. Treatability also varies within species and within trees. Softwoods are generally less suitable than hardwoods [21]. This is explainable in the sense that softwoods are made up by tracheids with a length of a few millimeters and a small tang. diameter of about 40 - 50 μm (Fig. 1, 2). For penetration any liquid has to pass the connecting bordered pits with their small openings in the membrane. Only the more permeable sapwood can be treated. The influence of the radial ray cells for permeation depends on species.

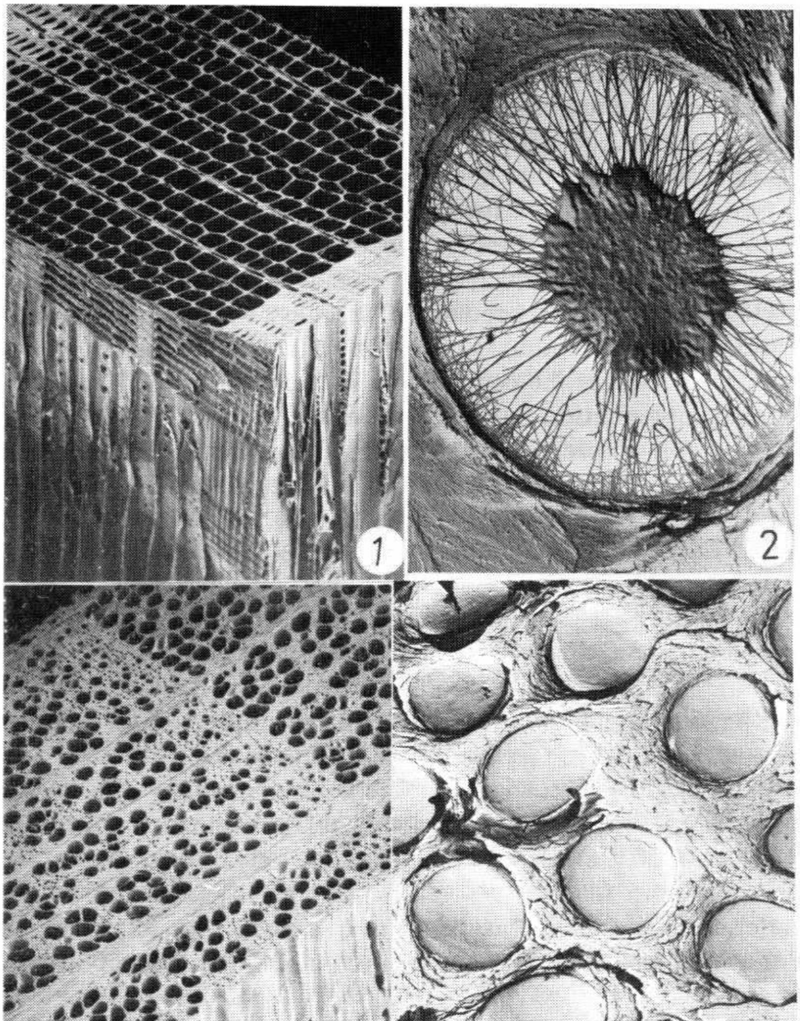

Fig. 1. Structure of softwood
Ryc. 1. Budowa drewna iglastego

Fig. 2. Pit membrane between softwoods tracheids
Ryc. 2. Błona jamki pomiędzy cewkami drewna iglastego

Fig. 3. Structure of a diffuse porous hardwood
Ryc. 3. Budowa drewna liściastego gatunków rozpierzchłonaczyniowych

Fig. 4. Pit membranes between hardwood vessels
Ryc. 4. Błony jamki pomiędzy naczyniami drewna liściastego

In hardwoods the axial flow is much facilitated through the larger vessels (Fig. 3). In comparison with the softwoods, their greater size and length ease the penetration considerably (Tab. 1). The vessels in diffuse porous wood have a tang. diameter about 100 μm, like *Fagus sp.* and *Populus sp.* and length of around 30 cm, but in ring-porous woods a tang. diameter – 300 μm with a length of about 3 - 10 m and more. The vessels of certain species have scalariform perforations and they are connected with each other by numerous pits with a solid membrane structure (Fig. 4). Both can have a limiting effect on penetration.

Table 1

Structural indications for the penetrability of wood materials mean values
Strukturalne wskaźniki przenikalności materiałów drzewnych – wartości średnie

Material Materiał	Lumina Światło %	Tangential diameter Wymiar styczny μm	Length Długość
Softwood tracheids Cewki drewna iglastego	60 – 70	40 – 50	3 – 4 mm
Hardwood Drewno liściaste – diffuse-porous vessels – rozpierzchłonaczyniowe	20 – 30	50 – 100	30 – 60 cm
– ring-porous vessels – pierścieniowonaczyniowe	15 – 30	200 – 350	3 – 10 m
Bamboo vessels Naczynia bambusa	5 – 19	100 – 200	30 – 60 cm
Rattan vessels Naczynia rotangu	15 – 20	150 – 500	?

The percentage of vessel area on a cross-section varies between 8% in *Quercus robur* L., 12% in *Fraxinus excelsior* L., 24% in *Betula pendula* Ehrh., 31% in *Fagus silvatica* L. and in 34% *Populus nigra* L. The porous structure facilitates much an easy penetration (Tab. 1). The radial penetration in hardwoods, in contrary, is almost nile. During impregnation the vessels will be filled up, whereas the surrounding tissue of parenchyma and fibres generally is empty. Information can thus be obtained about the arrangement of the vessel system by dissolving the woody tissue, like heating in concentrated nitric acid, whereby only a resin casts of the vessel system remains [23]. For an efficient penetration the porous structure must be free of occlusions, which can develop as tylosis or slime during storage and seasoning of the hardwoods. Their influence on the permeation of *Populus tremula* L. by a polystyren composite was shown by Ławniczak [16].

THE STRUCTURE OF BAMBOO AND RATTAN

The structures of dicotyledons as above differ principally to those of monocotyledons.

The stem of monocotyledons consists only of a primary tissue due to apical growth. There is no secondary growth due to the absence of a cambium, so that the stem elongates with its final diameter. The transport-system for water and the assimilates is only axially oriented with no radial pathways, like the rays in wood. There is no bark for outside protection of the stem. A very hard skin, the epidermis, safeguards the water-saturated tissue of the stem, but prevents also any sideways penetration of liquids.

This principle structural make-up becomes modified, if one considers in detail the anatomy of the two plant groups here in question, namely bamboo and rattan. Bamboo is a giant grass, but rattan belongs to the climbing palms. In the following for both groups those structural features will be briefly outlined, which are significant for the penetration of monomers in order to obtain polymer composites. In Table 1 some estimates for wood, bamboo and rattan are given, which characterize their different penetrability.

THE PATHWAYS OF BAMBOO

There are about 1.200 bamboo species of 70 genera, but their growth follows the pattern of a simple grass. The culm elongates only during few weeks until its final height has been reached, which can differ between few meters up to about 30 m. The young culm will "mature" during the following two years, by which increasing lignification will harden the tissue. Its size, however, will not change during life-time. The culm of bamboo is divided into internodes with a lenght of about 10 cm upto 100 - 150 cm and nodes between (Fig. 5). The outermost cells of the internodes are covered by a cutinized layer with a waxy coating. The stomata appear occluded. The inner lining of the culm wall consists of a continous zone of sclerenchymatic or parenchymatous cells. Pathways for penetration are only the crossends of culm segments and hardly the sheath scars around the nodes. Detailed information exists about the anatomical structure of a bamboo culm and its implications for the treatability with preservatives [e.g. 3, 6, 7, 8, 19].

Water and assimilates are transported in vascular bundles, consisting of two larger metaxylem vessels, smaller protoxylem elements and surrounding fibre sheaths resp. bundles (Fig. 7, 8). The vascular bundles are embedded in a ground parenchyma. Their location and also size changes from large bundles with larger vessels at the inner side of the culm to smaller and more crowed bundles with smaller vessels, but often larger fibre sheaths towards the periphery (Fig. 6). Within an internode the vessels are strictly axially orientated with no branching or deflection, they provide easy pathways for liquid movement, especially in fresh condition. The vessels themselves consist of short cell elements connected by simple openings, so that any liquid can pass freely within the internode. At the nodes, however, only few vessels ran straight--through into the following internode. Most turn into the nodal plate, the diaphragm, and become structurally modified by shortening the indiviudual vessel segments and by branching [10]. Any liquid movement through these

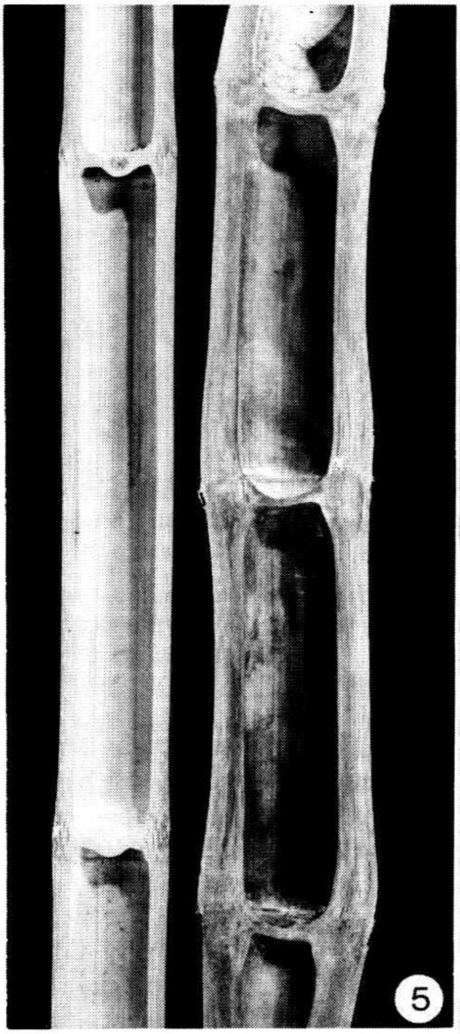
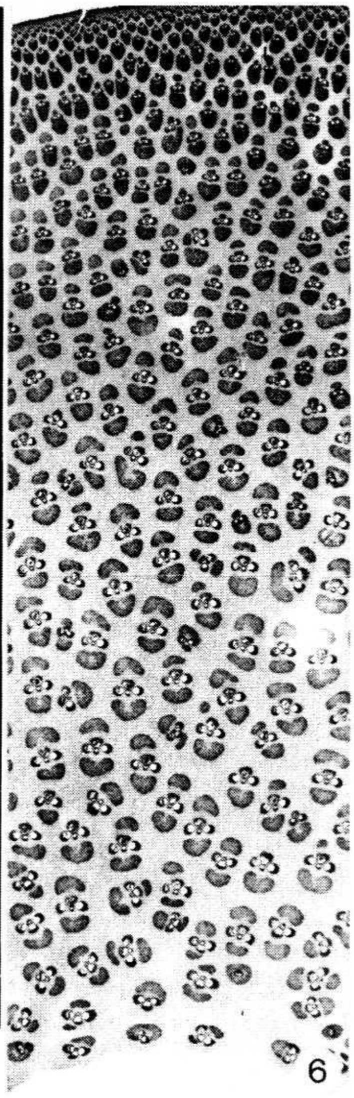

Fig. 5. Split bamboo culm with internodes and nodes
Ryc. 5. Rozłupany pęd bambusa z węzłami i międzywęzłami

Fig. 6. Cross section of a culm wall with vascular bundles and ground parenchyma
Ryc. 6. Przekrój ściany pędu z wiązkami naczyniowymi i miękiszem

twisted structures is considerably hindered. Even waterborne preservatives are often stopped at the nodes. The possible flow of the different monomers through the nodal area has not been investigated yet. Such information is needed for evaluating the passage of the various liquids for a treatment of culm segments with nodes.

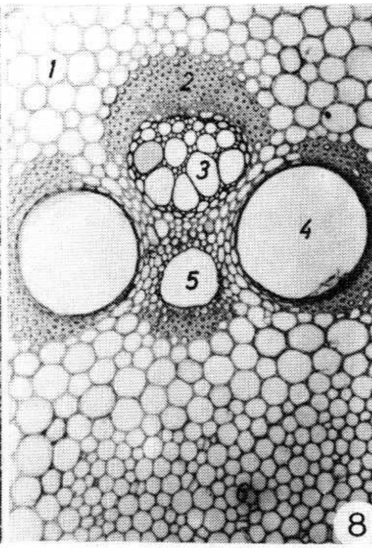

Fig. 7. Vascular bundles with vessels, fibre sheath and fibre bundle embedded in parenchyma
Ryc. 7. Wiązki naczyniowe z osłonami włókien i wiązkami włókien

Fig. 8. Details of a vascular bundle: 1 – ground parenchyma, 2 – fibre sheath, 3 – phloem with sieve cells and compagnion cells, 4 – metaxylem vessel, 5 – protoxylem element, 440x
Ryc. 8. Szczegóły wiązki naczyniowej: 1 – miękisz, 2 – osłona włókna, 3 – łyko z komórkami sitowymi i komórkami towarzyszącymi, 4 – naczynie metaxylemu, 5 – element protoksylemu, 440x

Most bamboo culms are hollow within the internode and have tight cell layers wall around a central cavity, only few species are solid, like *Dendrocalamus strictus* and *Chusquea sp.* In the vertical the thickness of the culm wall becomes smaller. As a result the inner part of the wall with the larger vessels will be reduced so that the upper culm portion contains more smaller vessels and also more fibres, providing a higher strength and flexibility. Consequently, the percentage of the various cell types varies not only accross the wall but also with the height of the culm.

Very general, a bamboo culm is composed of 50% parenchyma, 40% fibre and 10% conducting cells, eg. vessels and phloem [3]. Considerable differences exist between species. For liquid/monomer penetration the two metaxylem vessels of a vascular bundle are most important. They occupy a rather low percentage of the total area of about 3 - 5% at lower internodes and 6 - 12% at higher internodes (Tab. 1). Although these figures differ much according to species and the pattern within a culm less than 10% of a cross-section are available for the penetration of monomers. This underlines the restricted penetration of monomers into a bamboo culm. Also Liao and Peng [5] have stated a close relation between size of vessel and monomer loading. The same limitation applies also to the axial treatment of fresh bamboo culms by sapdisplacement with waterborne preservatives. In order to protect the 90% remaining tissue outside the treated vessels, the preservative must have a good diffusion capacity, so that mostly boron containing mixtures are applied. In case of monomers, however, it has to be clarifed, to what extent a diffusion outside of the vessels can take place. A penetration of only the vessels will certainly reduce water uptake and oxygen supply for a fungal attack, but the effect on technological properties will be less. In addition, the particular species of bamboo and the position of the culm segment to be treated will influence the possible monomer loading and its related effects.

As for wood, the bamboo can also develop tylosis and gum-like substances as cellular reactions during ageing, and after harvesting during seasoning and dying of the culm. The consequences of such occlusions on the penetration of liquids have not been considered so far, even not for the long-term practice of bamboo treatment with preservatives. Since the origin of the material to be treated, like age and storage condition is hardly known, these cellular reactions could influence considerably the results and their interpretation.

THE PATHWAYS OF RATTAN

A rattan stem exhibits a certain similarity with a bamboo culm, but it is quite different by its origin and structure. Rattans are climbing, spiny palms of the tropical rain forest of the paleotropics, consisting of about 13 genera with ca 600 species. The plant has a continous apical growth and reaches a length between half a meter upto 100 m and more. Unlike bamboo the stem is covered with layers of spiny leaf sheaths, which have to be removed before any processing. All rattan stems are solid and nearly cylindrical. Their diameter varies with the species from about 0,5 cm to 15 cm.

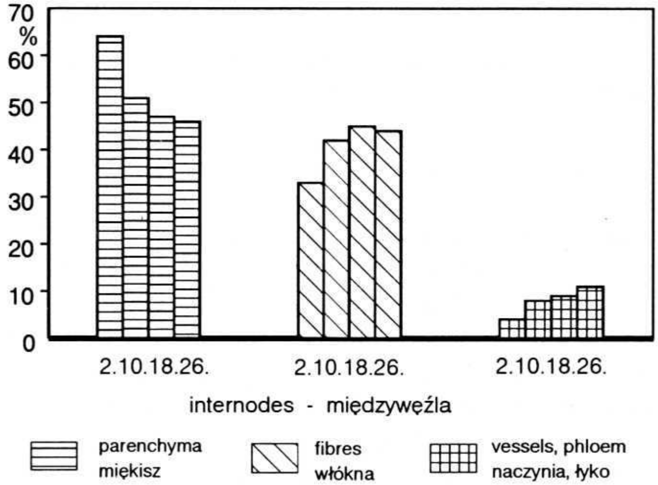

Fig. 9. Percentage of cell types from base to top internodes
Ryc. 9. Procentowy udział typów komórek od podstawy do międzywęźli u wierzchołka

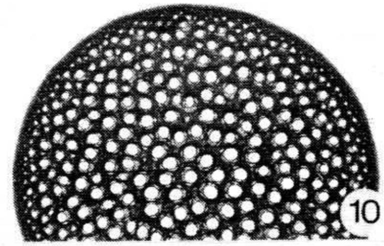
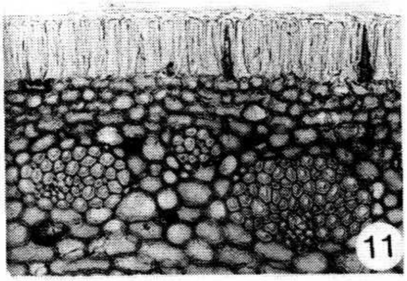
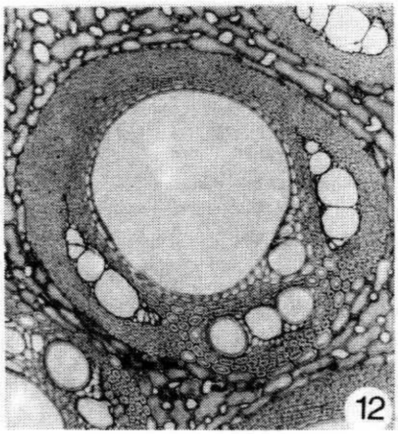
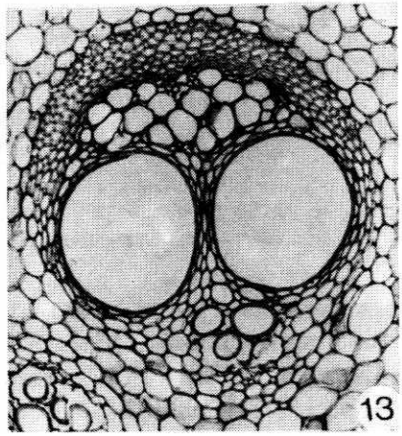

Fig. 10. Cross section of a rattan stem with vascular bundles and ground parenchyma
Ryc. 10. Przekrój poprzeczny pędu rotangu z wiązkami naczyniowymi i parenchymą

Fig. 11. Epidermis and cortex
Ryc. 11. Naskórek i kora

Fig. 12. Vascular bundle with one metaxylem vessel and two phloem-fields
Ryc. 12. Wiązka naczyniowa z jednym naczyniem metaksylemu i dwoma polami łyka

Fig. 13. Vascular bundle with two metaxylem vessels and one phloem-field
Ryc. 13. Wiązka naczyniowa z dwoma naczyniami metaksylemu i jednym polem łyka

Detailed anatomical studies were undertaken mainly in a comprehensive anatomical investigation of all 13 genera by Weiner & Liese [27, 29, 30, 31] and for species of the genera *Calamus* by Bhat et al. [1, 2].

A cross-section of a stem can be divided into an outer part, termed cortex and a central one (Fig. 10). The cortex is covered by an epidermis, consisting of one layer of unlignified cells with only few stomata between. The outer wall is either impregnated with SiO_2 or covered by a layer of wax (Fig. 11). The subepidermal zone is composed of lignified parenchyma cells with small fibre bundles. This zone provides considerable strength and also a tight sealing of the central part against loss of moisture or – vice versa – the side ways penetration of liquids during the treatment of a cane. The central corpus presents the typical structure of monocotyledons with vascular bundles embedded in a parenchymatous ground tissue. Average figures for the various cell types can hardly be accurate due to the variation that exists between species and within a culm. Cum grano salis 20 - 25% fibres, 30 - 35% parenchyma and around 45% vascular bundles give a rough estimate. For the purpose of this presentation the vessels as pathways for penetration are of interest. The vessels are part of the vascular bundles with the additional phloem surrounded by a fibre sheath and parenchyma. They comprise about 15 - 20% of a stem, which has consequently a more porous structure than a bamboo culm with 5 - 10%. The make-up of the vascular bundles is unique among all the many palms, since there are distinct differences among all the 13 genera, which have even generic characters [30]. Thus, the metaxylem consists of one or two vessels accompanied by one or two phloem fields (Fig. 12, 13). Rattans with two vessels have thus a greater capacity of liquid uptake. A cross-section of a culm reveals that the outer vessels are somewhat smaller than the inner ones, but with less difference than present in a bamboo culm. Longitudinally only a very small increasing trend can be noticed in the size of metaxylem vessels at the central part of the stem. The diameter of vessels ranges from 150 to 500 μm (Tab. 1). Noteworthy for considering the pathways of penetration is the orientation of the vessels, which follows the typical palm pattern. Whereas in bamboo the vessels run straight through an internode with connections only in the nodal part, in rattans the vessels exhibit a slight spiral orientation from the inner part outwards to the leafsheaths with branching by anastomoses. A penetrating liquid within a rattan stem is consequently more dispersed than within a bamboo culm.

To be mentioned is also the ground parenchyma with about 30 - 35%. It shows among the various genera three different types of cellular arrangement [27, 30]. The so – called type A consists of parenchyma cells with large intercellular spaces between, type B and even more C with smaller ones. They could be pathways for penetration, but their permeability has not been investigated so far. Common for both rattan and bamboo are possible cellular reactions by ageing or by wounding. Thus, also a rattan stem can develop tyloses and gum-like substances, which hinder penetration. The possible consequences of such structural alterations in permeability studies have not been considered yet.

PRACTICAL CONSEQUENCES

Bamboo and rattan are plant resources of greatest importance for the producing countries and the welfare of their rural population. Every effort to overcome the wide-spread impression of cheap materials with low quality appears justified. Investigations to produce value-added products by polymer-modification are very timely. Such efforts must be based on some considerations:

– The permeablity of bamboo and rattan is restricted to an axial penetration. The vessels comprise only a small area of the cross section. The possible polymer loading will much depend on their porous structure since the diffusion of monomers into the surrounding tissue is much restricted. Even for wood a polymer impregnation does not provide complete resistance towards biological deterioration. The bioprotective action of those substances depends mainly on limiting the acces of water to the wood tissue for fungal invasion as a prerequisite [11, 12]. The bamboo and rattan samples treated so far have a rather short length, hardly suitable for practical use. The depth of axial penetration has to be investigated, according to species and sample origin as well as the influence of nodes in bamboo and anastomoses in palms.

– The treatment itself requires air-dry material and a closed cylinder for applying the necessary vaccum and pressure which needs special handling and investment. For certain purposes only the lower cross-ends have to be treated which are endangered due to soil contact. For such purpose a vertical cylinder filled at a low level with the monomer would be suitable, as proposed by Ławniczak [14, 15]. Similar pressure plants are in use for wood preservation.

– Bamboo and rattan grow fast and are generally available at lower costs, so that even a preservation with preservatives for increasing the service life finds only a restricted application due to economic reasons. The production of bamboo/rattan-polymer composites would increase the material costs considerably. Therefore only selected fields of application would merit such a quality improvement.

– For rattan a stabilization of furniture parts could be considered and generally an application for wider end uses. Also the improvement of those rattan species which are disregarded and neglected as non-commerical due to their inferior technological properties and unsuitable anatomical make-up should be evaluaed [28].

– As for bamboo, the quality and service life of poles for horticulture and vineyards could be improved. It is estimated, that in Europe more than 20 mill bamboo poles (210 - 240 cm) are imported annually for fruittrees. Also 100 mill grapes are planted in Europe annually, and of these 40 mill could be supported by bamboo poles (1,50 m). These high figures result from the necessary replacement due to a restricted service life at the base. Finally, bamboo splinters are needed to support flower plants, alone for *Begonia* about 250 mill pieces annually in Germany and even more in Danmark or the Netherlands. These sticks have the disadvantage of an easy infestation by the mould fungus *Botrytis*. Again, an improvement without toxic substances may provide an interesting niche.

– Supposed an adequate treatment technology will be available for the quality improvement of bamboo and rattan, the decisive factor for such practical application will be the economy of the final product. Bamboo and also rattan are still available at relatively low costs, although the situation will change with the diminishing resources and the increasing wages. This pattern may also have influence on the prospects of bamboo and rattan-polymer composites.

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BAMBUS I ROTANG – ASPEKTY BIOLOGICZNE DOTYCZĄCE POPRAWY JAKOŚCI NA DRODZE NASYCENIA POLIMEREM

Streszczenie

Przedstawiono budowę anatomiczną bambusa i rotangu w aspekcie możliwości zwiększenia ich odporności na rozkład biologiczny. Bambus w swej łodydze nie zawiera żadnych substancji zwiększających jego odporność na działanie grzybów i owadów. Bambus i rotang są obecnie najtańszym materiałem naturalnym. W Europie istnieje obecnie popyt na około 20 milionów sztuk słupków do celów ogrodniczych i około 40 milionów sztuk słupków do hodowli winorośli. Praca omawia aspekty budowy anatomicznej roślin z punktu widzenia ich impregnacji styrenem. Zwiększenie trwałości bambusa i rotangu ma olbrzymie znaczenie zarówno dla krajów Azji, jak i Europy.

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