ABSTRACTS (PH D THESIS)

Anatomical and Mechanical Features of Palm Fibrovascular Bundles

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The palm family (Arecaceae, Palmae) consists of approximately 184 genera and 2400 species, is an important family of moncotyledon and palm plays an essential role in daily life of millions of people in tropical and subtropical regions. The properties and commercial utilization of palms are influenced by its structural characters. Until now researchers put most of their attention on the structural biology of commercial palms and there are many publications on oil palm (*Elaeis guineensis*) and coconut palms (*Cocos nucifera*). Tomlinson *et al.* [1, 2] did great research on the stem anatomy of palms. However, the anatomical and mechanical properties of fibrovascular bundles from leaf-sheath of palms, specially the palms widely distribute over the world, has not been studied well. In this thesis, the anatomical characteristics, mechanical properties and their functional implications were presented. This whole set of knowledge in palm leaf-sheath fibrovascular bundles could facilitate further understanding of archeological palm fiber-based products and utilization of these widespread natural fiber resources in future.

Cell wall characterization of leaf fibers in palm and its functional implications [3]

The fibrovascular bundles from the lignified leaf sheath of windmill palm (*Trachycarpus fortunei*) are widely used as natural fibers for various products, and exhibit excellent durability. In this study, the cell wall of windmill palm fibers was characterized using transmission electron microscopy (TEM, 2000EX II, JEOL Co. Ltd, Tokyo, Japan), high resolution field emission scanning electron microscopy (FE-SEM, JSM-6700F, JEOL Co. Ltd, Tokyo, Japan), and polarized light microscopy (PLM), and chemical analysis to measure lignin content. It was found that (1) the secondary wall was composed of just two layers (Fig. 1), outer (equivalent to S_1, 0.65±0.12 μm) and inner (equivalent to S_2, 1.28±0.30 μm) ones, with a high ratio of S_1 to the whole cell wall thickness; (2) the microfibrils of the S_1 are orientated in an S-helix (MFA, 127.0°±2.0), and those of the S_2 in a Z-helix (MFA, 43.7°±2.2); and (3) the Klason lignin content of fiber bundles was very high (nearly 40%). It is suggested that these structural and chemical features of windmill palm fibers are involved in their mechanical properties such as high flexibility and elasticity, and also related to their high durability.

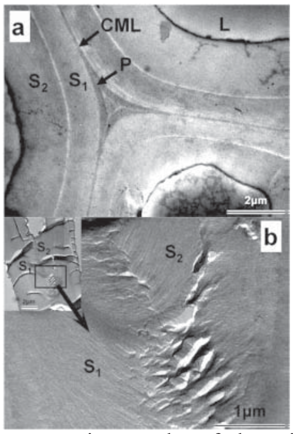

Figure 1. Electron micrographs of the windmill palm fiber. – a: Transverse section clearly shows a two-layered structure of the secondary wall. CML: compound middle lamella; L: lumen; P: primary wall; S1, S2: outer and inner layers of the secondary wall. – b: Enlargement of the fiber tip in oblique section, demonstrating microfibril orientation in the two layers of the secondary wall [3].

The cell wall organization of leaf sheath fibers in different palm species was also studied with PLM and TEM. The secondary wall of the fibers consisted of only two layers, S_1 and S_2. The thickness of the S_1 layer in leaf sheath fibers from the different palm species ranged from 0.31 to 0.90 μm, with a mean value of 0.57 μm, which was thicker than that of tracheids and fibers in secondary xylem of conifers and dicotyledons. The thickness of the S_2 layer ranged from 0.44 to 3.43 μm, with a mean value of 1.86 μm. The ratio of S_1 thickness to the whole cell wall thickness in palm fibers appears to be higher than in secondary xylem fibers and tracheids. We suggest that the two-layered structure in the secondary wall of palm leaf fibers, which presumably also applies to the homologous fibers in palm stems, is a specific character different from the fibers in other monocotyledons (such as bamboo and rattan) and dicot wood [4].

Mechanical characteristic of fibrovascular bundles among different genus in palm and its structural implications

This thesis also presented mechanical properties, microfibril angles (MFAs) and Klason lignin contents of leaf sheath fibrovascular bundles from 14 palm genera.

Observed by light microscopy, all fibrovascular bundles consisted equally of thick-walled sclerenchyma fibers and vascular tissue, while the shape and localization of vascular tissues on the transverse sections varied among species. It was possible to group these fibrovascular bundles into 3 types based on the vascular tissue's differences[5]: type A – rounded in the central region; type B – angular in the marginal region; and type C – aliform in the central region (Fig. 2). These three anatomical types of fibrovascular bundles showed some correlation with a current phylogenetic classification of palm species. Through mechanical tests, this research confirmed the correlation between diameter and mechanical properties of the fibrovascular bundles of palms; tensile strength and Young's modulus showed a decreasing trend with increasing diameter. We clarified that this trend was due to a marked increase in the proportion of transverse sectional area comprised by vascular tissue with increasing diameter of fibrovascular bundles. The MFAs of fibrovascular bundles ranged from 10.3º to 47.1º, which were generally larger than those of non-woody plants, conifers, and broad-leaved trees. The Klason lignin contents of palm species were also high, ranging from 18.3% to 37.8%, with a mean value of 29.6%. These large MFAs and high lignin contents could lead to the long-term plastic deformation and relatively low tensile strength of palm fibrovascular bundles. The observed MFA features might also have a relationship with the biomechanical movements of fiber bundles in the windmill palm[7].

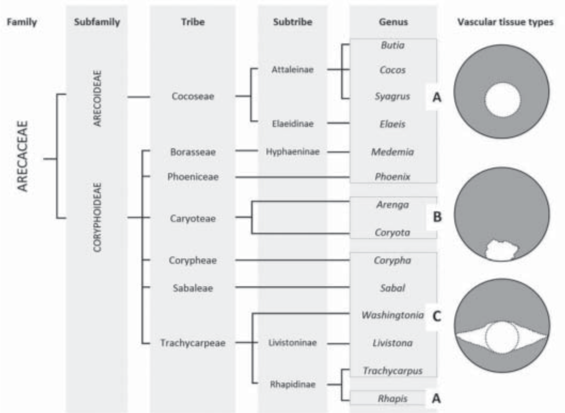

Figure 2. A diagram to show the phylogenetic classification of 14 genera of palms (Arecaceae), redrawn from Dransfield *et al.* [6] and Tomlinson *et al.*[2]. A, B, C indicate the three types of vascular tissues in fibrovascular bundles, where the gray area is occupied by sclerenchyma fibers and the white area by a vascular tissue.

Acknowledgements

The author thanks Prof. Keiji Takabe, Hiroyuki Yano, Kenji Umemura, Tuyoshi Yoshimura, Bunzo Mikami, Kentaro Abe, Aya Yanagawa for helping to carry out different experiments in their labs, Kyoto University. Also there are many thanks to Dr. Yoshiki Horikawa, Misao Yokoyama and Rie Endo for the resin embedding method and TEM observation. This research was supported by the G30 Program of the Faculty of Agriculture, Kyoto University, and the Kambayashi Scholarship Funding.

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