

(続紙 1)

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論文題目	VARIATION OF FIBER PROPERTIES IN RELATION TO THE DISTANCE FROM VESSELS IN ACACIA MANGIUM (アカシア・マンギウム木繊維の道管との距離による性質変化)		
(論文内容の要旨)			
The <i>Acacia</i> plantation in Indonesia requires a tree improvement program to increase the yield of solid wood and its quality to meet market demands. In the plantations operating on Sumatra Island in Indonesia, the plantation program remains primarily in the selection step, and has not yet implemented the breeding step. Another problem of these plantations is that trees are primarily selected based on growth rate and stem form. Hence, the improvement of wood quality to meet end-product requirements is still in progress. For instance, a trial hybrid of <i>A. mangium</i> and <i>A. auriculiformis</i> are growing. Its stem form and growth rate show that this <i>Acacia</i> hybrid is promising, and tends to produce better quality raw material for pulp and papermaking compared to its parents. However, to date, little is known even regarding basic properties, such as density, anatomy, and chemical composition of the hybrid in Indonesia. The objectives of this study are as follows; (1) evaluating wood properties of the <i>Acacia</i> hybrid, in parallel to searching for specific anatomical predictors of pulp yield and paper strength applicable to this species, (2) introducing a facile, quick, and reliable technique to obtain 3D reconstructed data from serial optical micrographs to investigate the above mentioned relationships, and (3) investigating fiber length in tangential direction, fiber diameter, fiber wall thickness and chemical composition, and MFA in relation to the distance of fibers from vessels. In Chapter 2, the basic properties of the <i>Acacia</i> hybrid were investigated. Compared to both parents, <i>A. mangium</i> and <i>A. auriculiformis</i>, the <i>Acacia</i> hybrid had longer fibers, in addition to a higher slenderness ratio, fiber proportion, and holocellulose content, but smaller proportions of vessels, parenchyma cells, and extractives. In addition, the hybrid tended to have a thinner cell wall, and a lower proportion of ray cells, rigidity, and lignin content, but a higher flexibility coefficient and wood density compared to <i>A. mangium</i>. Fiber length was positive & negative correlation with α-cellulose and lignin content, respectively. Holocellulose content was all reliably predicted by fiber length. The slenderness ratio was a better predictor of extractive content than fiber length. Both the fiber length and slenderness ratio were better predictors of chemical composition than wood density. Therefore, fiber length and the slenderness ratio could be used as reliable predictors of pulp yield and paper strength for acacias. Chapter 3 was focused on a more detailed search of the anatomical factors, with special reference to fiber length by exploring <i>A. mangium</i>. A newly developed 3D microscopy technique was introduced to create aligned serial images from the cross sectional micrographs. Reconstruction of 200 serial images took just 1 day, and all digital information was compiled in a personal computer. This dataset allowed us to quickly and easily estimate wood fiber length using a public-domain software. It took no more than 2 min to locate the 2 tips of a fiber, by scrolling images on the			

computer, which contrasts against previous studies of serial cross sections. Given this technical development, fiber length variation in relation to the distance from vessels was measured in detail. Fibers that were more distant from vessels were found significantly longer, not only in the radial direction, but also in the tangential direction.

In Chapter 4, the diameter and wall thickness in relation to distance from vessels were evaluated. It was often difficult to measure the radial and tangential direction of the diameter of fibers that were in close proximity to vessels because of deformation. Then, around a vessel, the diameter and cell wall thickness along the radial and tangential direction of the vessel was evaluated and compared. The change in cell wall thickness of 1 fiber was also measured from the serial cross sections. The results showed that fibers adjacent to vessels were significantly wider in diameter and thicker in wall thickness along the direction parallel with vessel enlargement than those distant from vessels in both radial and tangential directions. Wall thickness along the fiber length was found to vary in both fibers adjacent to and distant from vessel, whereby wall thickness was greatest at the center, and gradually decreased toward the tip of the fiber cell.

The characterization was further extended to the chemical composition and MFA in relation to the distance from vessels, and the results were discussed in Chapter 5. The chemical composition was evaluated from microscopic FTIR spectra, on the basis of the specific bands for lignin 1505 cm^{-1} and cellulose and hemicellulose at 1060 cm^{-1} and 1034 cm^{-1} . Combined FT-IR and PCA analyses were successfully applied to analyze the local chemical compositional differences in fibers adjacent to and distant from vessels. The fibers adjacent to vessels had higher lignin and MFA content, but lower carbohydrate content compared to fibers that were distant from vessels.

In search of the superiority of *Acacia* hybrid than its parents as a resource for pulp and papermaking, the microstructure of *A. mangium* were thoroughly investigated, vessels influence the anatomical features such as length, diameter, and cell wall thickness in both the radial and tangential direction, although these influences were more tailed in the radial direction in addition to MFA and chemical composition. Therefore, to produce high quality pulp and paper, I suggest that the quantity of vessels in the *A. mangium* tree should be reduced through tree improvement breeding programs.

(論文審査の結果の要旨)

インドネシアのアカシア植林では材容積と品質向上にむけた選抜が続けられている。本研究ではアカシア・マンギウム品種選抜に向けた従来の生育環境や遺伝的な取り組みとは異なり、解剖学的な立場から、紙・パルプ材としてのアカシア材の選抜指標を見いだそうとしたものである。特に、木繊維の特徴変化を道管からの距離をパラメータとして、細胞レベルで3次元的に詳しく解析した。本研究の評価できる点は、以下の4点である。

1. パルプ・紙用材として、樹形や生長量から母樹より優れるとされるマンギウムとアウリカリフォルミスの自然交配品種、ハイブリッドの解剖学的特徴を調査し、他の2者と比較して、道管が少なく、リグニン含量が低く、木繊維が長く、細胞壁が薄く、スレンダー比(長さ/直径)が高いことを明らかにした。
2. アカシア・マンギウムの木繊維の特徴を、道管との相互作用をパラメータとして個々の細胞レベルで詳細に解析するため、連続切片法を用いた新規な計測法を考案した。具体的には計算機内で連続切片像を三次元情報に再構築することにより、繊維の長さ、壁厚など一連の計測作業の効率化を達成した。
3. 木繊維の性質は、道管から放射方向、接線方向への距離に応じて変化し、近傍では道管の影響を受けて横断面形状が扁平化し長さも短い、道管の影響が小さい遠方では、木繊維は長く、細胞壁が薄く、スレンダー比が高い利用上有用な繊維となることを細胞レベルで確認した。
4. 木繊維の化学成分とマイクロフィブリル傾角を調べ、道管からの距離に比例して、リグニン量は減少し、逆にホロセルロースが増加するとともにマイクロフィブリル傾角が減少する傾向を明らかにした。

以上のように、本研究はパルプ・紙用材の指標となる木繊維の性質の道管依存性を明確にした研究であり、樹木細胞学ならび木材利用学に寄与するところが多い。

よって、本論文は博士(農学)の学位論文として価値あるものと認める。

なお、平成24年2月15日、論文並びにそれに関連した分野にわたり試問した結果、博士(農学)の学位を授与される学力が十分あるものと認めた。

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要旨公開可能日： 年 月 日以降