In-situ Optical Measurement of Bamboo Leaf Health Status Using 1310-nm TD- OCT System

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Abstract: Bamboo is a versatile plant with applications ranging from construction to medicine and requires careful monitoring to maintain its health. The study focuses on non-invasive techniques for the early detection of unhealthy bamboo leaves, crucial for agricultural preservation. Using a Time Domain-Optical Coherence Tomography (TD-OCT) system, we conducted in-situ optical measurements on bamboo leaves to assess their health status. A-scan profiles obtained from TD-OCT showed differences in optical reflectance between healthy and unhealthy leaves. Unhealthy leaves showed decreased optical reflectance, suggesting a decline in the photosynthetic rate. Mixing of the epidermal and palisade layers was observed in unhealthy leaves compared to the distinct layers in healthy ones. Analysis obtained through an Olympus BX51 microscope highlighted unique characteristics distinguishing healthy and unhealthy bamboo leaves. While healthy leaves exhibited uniform color and structure, unhealthy leaves displayed discoloration and irregularities. Furthermore, through RGB analysis, R-G profiles revealed higher red intensity in unhealthy leaves, suggesting decreased chlorophyll content and further supporting impaired photosynthetic function. Overall, the study demonstrates the effectiveness of TD-OCT as a non-invasive and simple point measurement technique for assessing bamboo leaf structure and health. These findings provide valuable insights for health monitoring of bamboo plants, contributing to sustainable agriculture and conservation efforts.

Key Words: OCT, Bamboo, Plant Health, Non-invasive Imaging

1. INTRODUCTION

1.1 Background

Bamboo holds a special place in the Philippines, deeply woven into our environment, economy, and culture for centuries. It serves multiple purposes, from building materials to medicine, and supports many communities as a source of income. Bamboo's eco-friendly nature means it leaves a small carbon footprint, making it an environmentally sustainable choice. However, some communities are losing their bamboo resources due to a lack of information on how to grow and manage bamboo plantations. This highlights the need for sustainable solutions. More research is needed to speed up the development of bamboo plantations. Maintaining the health of bamboo plants, particularly detecting leaf diseases early, remains a challenge. Traditionally, methods for assessing leaf health have been subjective, time-consuming, and often inefficient. There is a growing need for non-invasive and accurate techniques to monitor bamboo leaf health. (Department of Environment and Natural Resources, 2016; Gutierrez, M. et al., 2020; Roxas, 2012; Virtucio, 2009)

Optical coherence tomography (OCT) is a non-invasive imaging technique used to visualize cross-sections of various materials. Initially developed for examining the retina, OCT has expanded its applications to different parts of the human body and non-medical fields. Time-domain optical coherence tomography (TD-OCT) is one such type of OCT. The main advantage of OCT is its ability to provide real-time, in vivo images without causing any damage to the material being examined. This is made possible by fast signal processing and high scanning rates. When applied to plants, OCT allows researchers to study plant structures without the need for cutting or damaging them, preserving their integrity. This non-invasive approach enables studies without interfering with the plant's growth or development. (Aumann, S. et al., 2016) In this study, Time Domain-Optical Coherence Tomography (TD-OCT) is employed to assess the health status of bamboo leaves

1.2 Objectives

General Objective

To characterize and differentiate healthy and unhealthy bamboo leaves using Time Domain-Optical Coherence Tomography (TD-OCT) and RGB analysis, with the aim of developing a non-invasive method for unhealthy bamboo plants.

Specific Objectives

- To measure the attenuation coefficient of healthy and unhealthy bamboo leaves using Time Domain-Optical Coherence Tomography (TD-OCT).
- To identify morphological differences between healthy and unhealthy bamboo leaves using the Olympus BX51 Microscope
- To conduct RGB analysis to assess color characteristics of healthy and unhealthy bamboo leaves.

1.3 Scope and Delimitations

This study focuses on the use of Time Domain-Optical Coherence Tomography (TD-OCT) and RGB analysis for assessing the health status of bamboo leaves. Specifically, it examines the optical properties and morphological characteristics of both healthy and unhealthy bamboo leaves. The study is conducted using a portable TD-OCT system to obtain high-resolution images of bamboo leaves without causing any damage. Additionally, RGB analysis is employed to analyze color characteristics as indicators of leaf health. The research is limited to bamboo leaves and does not extend to other plant species. It also does not cover the investigation of specific diseases or pathogens affecting bamboo leaves.

While this study provides valuable insights into the non-invasive assessment of bamboo leaf health using TD-OCT and RGB analysis, it has its limitations. The research is limited to the visual and optical characteristics of bamboo leaves and does not explore biochemical or molecular aspects of leaf health. Also, the sample size of bamboo leaves used in the study may not represent the entire population, thus limiting the generalizability of the findings. The research does not include a longitudinal study to assess changes in leaf health over time.

1.4 Review of Related Literature

Non-Invasive Techniques

Plant diseases are a concern for agriculture as it can result in economic losses and post-harvest damage. Early detection of these diseases is vital to maintaining agricultural sustainability. Traditional detection methods, such as molecular and serological techniques, are often time-consuming. In contrast, non-destructive techniques offer practical and efficient alternatives. These methods eliminate the need for sample preparation and repetitive processes, streamlining detection and reducing analysis time and effort. By enabling early disease detection and prevention, non-destructive techniques contribute to improved health control and optimized yields, reducing reliance on pesticides and pest management strategies. (Ali et al., 2019)

In a study conducted by Anna et al. (2019), the extinction coefficient of leaves undergoing senescence was investigated using spectral domain optical coherence tomography (OCT). The researchers focused on analyzing the microstructural changes in senescing leaves of the deciduous plant Acer serrulatum Hayata. Through A-scan images, they observed notable differences in the attenuation coefficient among green, yellow, and red leaves, indicating variations in light-scattering properties during the deterioration process. Specifically, there was a decrease in the attenuation coefficient as the leaves transitioned from green to red. This decline in attenuation coefficient correlated with the senescence process, reflecting changes in leaf structure and composition as leaves aged. Notably, the higher attenuation coefficient observed in green leaves suggested their healthier condition compared to yellow and red leaves, indicating a direct relationship between leaf health and attenuation coefficient (Anna et al., 2019)

In a more recent study, researchers utilized a portable TD-OCT system to assess healthy and unhealthy leaves of a Citrofortunella Microcarpa plant. They found that healthy leaves had higher attenuation coefficients compared to unhealthy ones, similar to the previous study. The comparison of A-scan profiles between healthy and unhealthy leaves indicated a mixing of the epidermal and palisade layers within the unhealthy leaves. (Galvez et al., 2021)

Principles of TD-OCT

Optical Coherence Tomography (OCT) is a non-invasive imaging technique that provides real-time, cross-sectional images of samples. It works based on low-coherence interferometry, using a Michelson interferometer with a broadband light source. In OCT, a superluminescent diode generates a beam of light, split into sample and reference beams by a 50:50 beam splitter. The sample beam passes through the sample, where it is reflected and scattered, then collected by a photodiode detector. Meanwhile, the reference beam hits a reflector or mirror and is also collected by the detector.

Unlike standard Michelson interferometers, the study uses a modified OCT with a rotating reference mirror, allowing for a longer scanning range and improved repeatability. The interference of the two beams creates a signal converted to an electrical one by a receiver circuit, then displayed on an oscilloscope. This interference pattern generates an A-scan, providing depth information at a single point. This process allows for the creation of detailed images revealing the internal structure of the sample. Figure 4 depicts the schematic diagram of the Michelson interferometer used in the OCT. (Fujimoto and Drexler, 2015; Shiina et al., 2003)

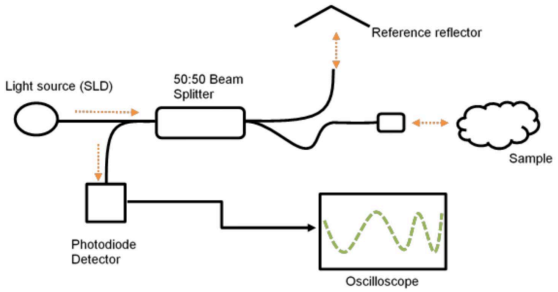

Fig 1. Diagram of the TD-OCT

2. METHODOLOGY

2.1 Leaf Collection and Classification:

Leaves from the vicinity of the De La Salle University (DLSU) campus were collected and stored in aluminum foil-covered containers to prevent further changes due to light exposure. Approximately 20 healthy

and unhealthy leaves were selected and classified from the collected samples. Each leaf was marked with a 1 x 1 cm^2 box, designating the region of interest (ROI) around the leaf lamina, specifically midway between the leaf tip and base. These marked points served as reference locations for obtaining scans of the leaf, ensuring consistency in measurements throughout the experiment.

2.2 TD-OCT Setup:

The TD-OCT system utilized in this study featured a 1310 nm Superluminescent Diode (SLD) manufactured by Anritsu Co. Ltd., with a spectral width of 106 nm. The axial resolution of the system, determined by the properties of the SLD, was approximately 7 µm in air, while the lateral resolution, dependent on the numerical aperture of the sample probe, was approximately 3 µm. The OCT system employed a rotating mirror for optical path scanning, with a scanning diameter of 10 mm and a scanning rate of 25 scans per second.

The leaves were positioned on microscopic slides for optimal imaging. The OCT probe was fixed in a vertical orientation and directed light downward onto the leaf surface. Each sample was carefully placed on a coverslip and secured with tape to immobilize it during measurements. Consistent distance between the probe and the leaf was also kept to ensure consistent readings.

2.3 Microscopy:

The same ROI of the leaves was observed under a microscope to provide clear images of the leaf surface morphology. These images were used to characterize changes in the leaf structure in relation to optical reflectance. Additionally, RGB profiles were obtained from the microscope to further analyze the color characteristics of the leaves.

3. RESULTS AND DISCUSSION

Healthy and unhealthy bamboo leaves were visually assessed for morphological differences using the Olympus BX51 microscope. Figure 2 shows a comparison between an unhealthy bamboo leaf (Figure 2a) and a healthy bamboo leaf (Figure 2b). The healthy leaf exhibits clear layering and uniform coloration, whereas the unhealthy leaf shows signs of discoloration and structural irregularities, with some veins showing bloating or even breakages. The same pattern was also observed on the other leaves.

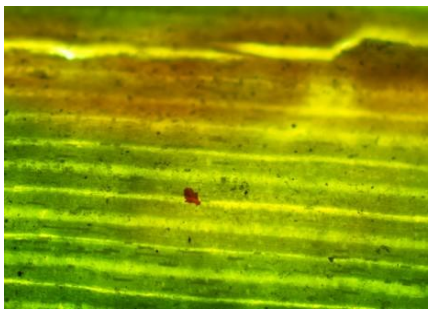

Figure 2a. Microscopic Image of Unhealthy Leaf

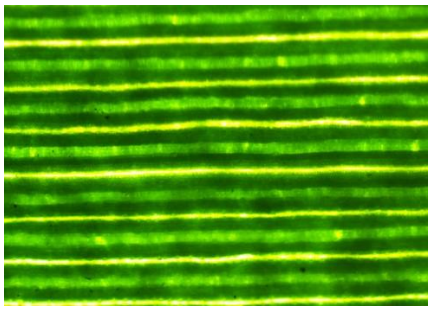

Figure 2b. Microscopic Image of Healthy Leaf

Time Domain-Optical Coherence Tomography (TD-OCT) was used to obtain A-scan profiles of the bamboo leaves. Figure 3 displays the A-scan profiles of an unhealthy leaf (Figure 3a) and a healthy leaf (Figure 3b). In the A-scan profile of the healthy leaf, distinct layers corresponding to the upper epidermis and palisade mesophyll are visible, indicating a well-defined leaf structure. However, the A-scan profile of the unhealthy leaf shows a mixing of these layers, suggesting structural abnormalities. By comparing the two A-scans, the layers in the healthy leaf are much more defined compared to that of the unhealthy leaf, signifying the mixing of the layers. The OCT was also able to give insight on the optical properties of the leaves, as unhealthy leaves exhibited lower optical reflectance, suggesting a decrease in photosynthetic rate.

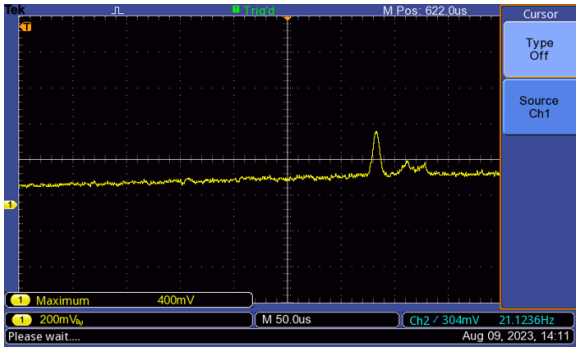

Figure 3a A-Scan of Unhealthy Leaf

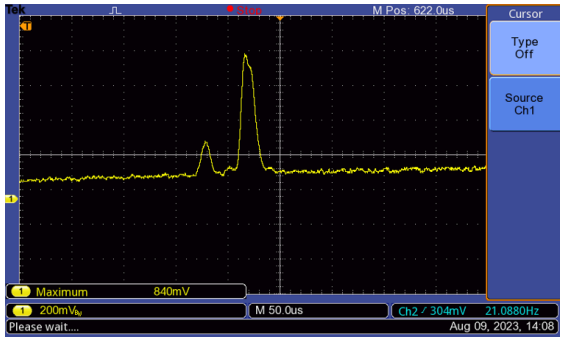

Figure 3b A-Scan of Healthy Leaf

Additionally, RGB analysis was conducted to characterize the color profiles of healthy and unhealthy bamboo leaves. Figure 4 illustrates the RGB profiles of a healthy leaf (Figure 4a) and an unhealthy leaf (Figure 4b). The healthy leaf exhibits uniform coloration across the RGB channels, whereas the unhealthy leaf shows variations in color intensity, particularly in the red channel.

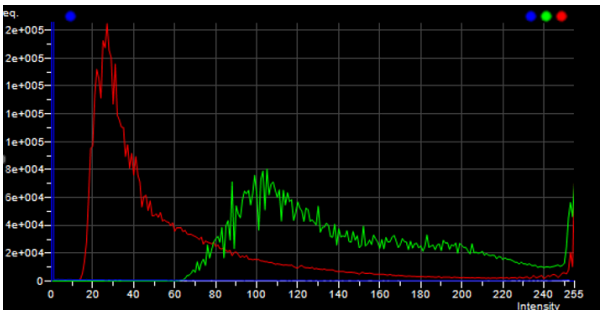

Figure 4a. R-G Profile of Unhealthy Leaf

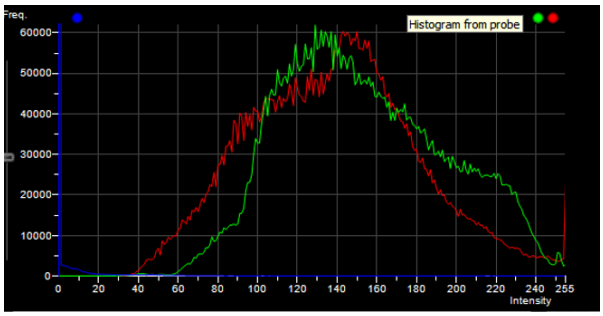

Figure 4b. R-G Profile of Unhealthy Leaf

Overall, these results demonstrate the utility of TD-OCT in assessing bamboo leaf health and provide valuable insights for early detection of plant diseases.

4. CONCLUSIONS

In conclusion, our study highlights the efficacy of Time Domain-Optical Coherence Tomography (TD-OCT) as a non-invasive tool for assessing the health status of bamboo leaves. Through the analysis of TD-OCT data, we were able to distinguish between healthy and unhealthy bamboo leaves based on differences in leaf morphology and optical reflectance. Healthy leaves exhibited distinct layers and higher attenuation coefficients compared to unhealthy leaves, which also showed a mixing of leaf layers.

These findings show the potential of TD-OCT as a valuable tool for early detection of plant diseases and monitoring plant health in real-time. By providing non-destructive and rapid assessment of leaf structure and properties, TD-OCT can aid farmers and researchers in implementing interventions to prevent disease spread and optimize crop management practices.

Furthermore, our study contributes to the growing body of research aimed at enhancing agricultural sustainability and biodiversity conservation. By better understanding the health dynamics of bamboo leaves, we can develop more effective strategies for bamboo cultivation and management, ultimately benefiting both local communities and the environment.

5. ACKNOWLEDGMENTS

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