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Transmittance Properties of Healthy and Infected Coffee Robusta Leaves with Coffee Leaf Miner (CLM) Pests †

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Abstract: Coffee Robusta (*Coffea canephora*) increased its total production by 73.5% during the first quarter of 2023. In this study, twenty (20) samples each of healthy and infected coffee leaf were measured for the transmittance properties in the UV-Vis and NIR regions. Coffee Leaf Miner (CLM) infected leaves were identified based on the translucent patches on the plant foliage. Results showed that a healthy coffee leaf haas a mean transmittance of 41.53 μW for the NIR region while for the infected leaves, the mean transmittance is 47.06 μW. Healthy coffee Robusta leaves showed significant difference in their transmittance properties compared to infected coffee Robusta leaves in the UV ($r = -0.15$, $p = 0.021$, $F = 5.8$, $t = -0.2.86$), visible ($r = -0.15$, $p = 0.018$, $F = 6.11$, $t = -2.88$), and NIR ($r = -0.14$, $p = 0.027$, $F = 5.28$, $t = -2.99$) regions. A CLM index was introduced based on the intensity ratio of green and red wavelengths. I535/575 showed positive correlation with the estimated chlorophyll-a concentration for healthy ($r = 0.94$, $p = 0.227$) and infected ($r = 0.56$, $p = 0.622$) leaves. This method leads to the development of portable sensors for early detection of CLM in plants.

Keywords: transmittance properties; early detection; coffee robusta; leaf miner pests

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1. Introduction

Coffee Robusta (*Coffea canephora*) is one of the four varieties of coffee cultivated in the Philippines. The others are arabica, liberica, and excelsa [1]. Based on the Philippine Statistics Authority (PSA) 2015 data, there are about 276,000 coffee farms in the country which comprises 77.4 million trees [2]. Among the three coffee varieties in the Philippines, Robusta is the most commonly planted which accounted for 73.5% percent of total production in 2023, Efforts have been made to revive coffee farming and improve the quality of Philippine coffee [1,3].

Over the years, the coffee industry in the Philippines faced several challenges, including Coffee Leaf Miner (CLM) (*Leucoptera coffeella*) and other diseases have periodically affected coffee crops, leading to reduced yields and quality and outdated farming practices, lack of access to modern technology, and inadequate infrastructure contributed to low coffee yields [4–6]. CLM moth larvae are the primary causal agent of the crop damage to coffee plantations [5]. The damage results from its larvae that feed on coffee leaves which reduces fruit production [6]. The larvae feed on the mesophyll of the coffee tree leaves and create mines [7-9].

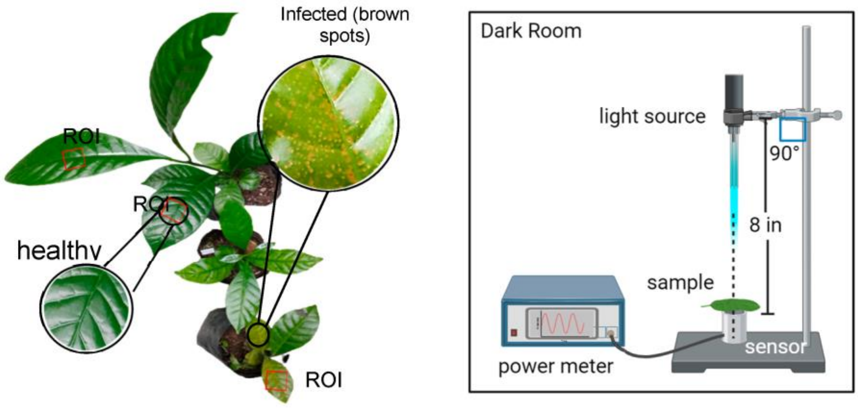
Having a method in detection of plant diseases is very important to lessen the possible impact to its production and can be done in various methods. Analysis of optical properties of plants can be done in two ways, destructive and non-destructive [10–13]. Destructive process includes microscopy and spectrophotometry that requires the actual sample plant to undergo different processes inside the lab [13]. On the other hand, the non-destructive approach incorporates the use of a portable sensor to determine the optical properties which is easier to be done and less time consuming [10–12]. Such methods stated above have been successfully used for early detection and diagnosis for plant health [14,15].

In this study, we aim to analyze the optical properties of healthy and infected Coffee Robusta Leaves using Thorlabs PM400 Optical Power Meter. Specifically, we identify the transmittance in the UV-Vis-NIR Spectrum to determine quantitatively the signature responses and characterize healthy and infected Coffee Robusta leaves. Statistical analyses such as t-test and Pearson's r correlation were used to determine differences in the healthy and infected coffee Robusta leaves. Lastly, the result from this study provides preliminary data for the development of non-destructive portable sensors in CLM detection.

2. Materials and Methods

2.1. Plant Identification

Coffee Robusta plants were verified and collected from the Department of Agriculture-Bureau of Plant Industry (DA-BPI), Manila, Philippines. The plants were placed inside the laboratory to acclimatize to ambient conditions. Twenty (20) leaf samples of each of the 6-month-old healthy and CLM infected plants were identified based on the translucent patches on the plant foliage. CLM reduces the photosynthetic leaf surface where brown spots are visible on the infected leaves. All leaf samples investigated were marked with region of interest (ROI) as shown in Figure 1a. The measurements were performed in a dark room to remove light noise.



(**a**) (**b**)

Figure 1. Experimental set-up of the leaf transmittance properties investigation of Coffee Robusta plants. (**a**) Region of Interest (ROI); (**b**) Setup.

2.2. Transmittance Properties

Transmittance spectra of healthy and infected leaves were measured with an optical power meter (Thorlabs PM400, Newton, NJ, USA) connected with S120VC standard photodiode power sensor. Leaf transmittance was analyzed through the UV-Vis and NIR spectrum wavelengths at 200–1100 nm wavelength interval. Healthy and infected leaves were placed individually at 90° by illuminating the adaxial surface about 8 inches to the High-Power Xenon light source (Ocean Insight HPX-2000, Orlando, FL, USA). Light passes through the leaf surface to the power sensor and the transmittance reading is reflected to the power meter as shown in Figure 1b.

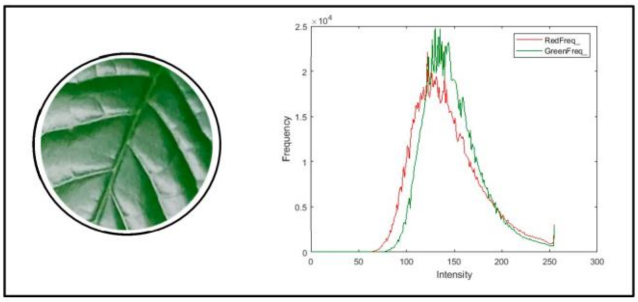
2.3. Statistical Analyses

The ratio between the normalized intensity values from green (535 nm) and red (575 nm) were calculated. Pearson's r correlation was used to compare the estimated chlorophyll content and the ratio for both healthy and infected leaves. T-tests for independent samples were computed for the transmitted power for the coffee leaves in the UV-Vis-NIR regions.

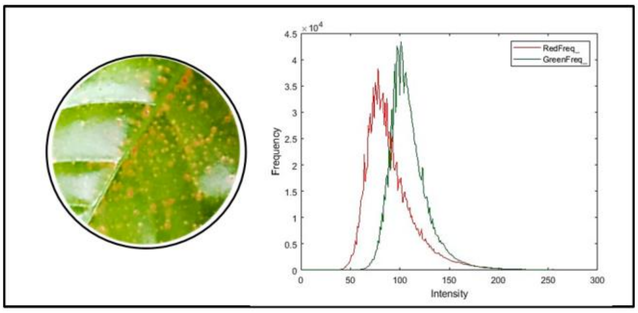
3. Results and Discussion

3.1. Microscopic characterization of Coffee Robusta Leaves

Under microscopic observations, CLM only invaded the upper dermis (Figure 2). The epidermal cells and the cell walls are destroyed due to attacks from the CLM [16]. To further analyze the morphological conditions of the coffee robusta leaves, transmission or scanning electron microscopies are recommended.



(**a**)



(**b**)

Figure 2. RGB intensity vs. frequency (**a**) Healthy Coffee Leaf; (**b**) Infected Coffee Leaf.

In this study, we introduce a CLM index (I535/575) by measuring the ratio between intensities from 535 nm (Green) and 575 nm (Red) as shown in Table 1. The normalized intensities in the red and green region varies for healthy and infected leaves. The CLM index showed positive correlation with the estimated chlorophyll-a concentration for healthy (r = 0.94, p = 0.227) and infected (r = 0.56, p = 0.622) leaves. This study showed a similar high correlation between chlorophyll content and RGB values as discussed in different literatures [17,18].

Table 1. Normalized Intensity of RGB data from Coffee Robusta Leaves (n = 20, p = 0.05).

RGB Data *	Normalized Intensity (a.u.)		I535/575	Chlorophyll-a Concentration (mg/L)
	Red	Green	Range (Mean ± St.Dev.)	
Healthy	0.27–0.96	0.31–0.98	0.81–0.97 (0.92)	0.34
Infected	0.08–0.16	0.30–0.85	0.26–0.39 (0.33)	0.12

* No significant change in the blue wavelength for both healthy and infected leaves.

3.2. Transmittance Measurements

Table 2 summarizes the transmittance measurements in the healthy and infected coffee Robusta leaves from the UV-Vis-NIR spectrum. The power measured using the transmittance of healthy and infected coffee Robusta leaves varies from UV, visible and near infrared spectrum. The spectral response of infected leaves is higher compared to healthy leaves. This is due to the breakdown of upper dermis and cell walls caused by CLM [19]. These results may affect the phenotype of leaves but also the photosynthetic ability of leaves to produce chlorophyll and other nutrients. The response of the near-infrared spectrum is significantly different from healthy and infected leaves, which can be used to understand early detection of pests, physiological disorders, and ozone damage [20–22].

Table 2. Transmittance measurements (μW) of healthy and infected coffee Robusta plants (n = 20, p = 0.05).

Robusta Leaves	Healthy			Infected		
Spectrum	**UV**	**Visible**	**Near-IR**	**UV**	**Visible**	**Near-IR**
Range	71.15–95.44	42.65–75.9	33.3–47.56	75.95–139.65	59.25–109	38.03–68.18
Mean ± St.Dev.	84.35 ± 6.95	65.96 ± 5.34	41.53 ± 3.26	95.06 ± 15.21	74.19 ± 11.91	47.06 ± 7.16
Variance	48.25	28.55	10.62	231.2	141.77	51.21
Skew	0.05	0.07	0.06	1.34	1.34	1.31
Kurtosis	−0.88	−0.78	−0.66	2.58	2.54	2.76

The relationship between healthy and infected coffee Robusta leaves were statistically measured using t-test. Healthy coffee Robusta leaves showed significant difference in their transmittance properties compared to infected coffee Robusta leaves in the UV (r = −0.15, p = 0.021, F = 5.8, t = −0.2.86), visible (r = −0.15, p = 0.018, F = 6.11, t = −2.88), and NIR (r = −0.14, p = 0.027, F = 5.28, t = −2.99) regions. This study is a good reference for the development of non-destructive techniques in agriculture and environmental monitoring.

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