Real-time Chlorophyll Fluorescence: Enabling Higher Quality Palm Oil During Production

September, 2024

ABSTRACT

Researchers from Singapore and Malaysia have developed and validated a novel approach for real-time, non-invasive monitoring of palm oil quality during the milling process using chlorophyll fluorescence spectroscopy. This method leverages chlorophyll's photo-response properties to directly probe palm oil quality without disrupting the production line. The technique integrates a sensor that detects changes in chlorophyll’s fluorescence, providing immediate feedback on key quality parameters such as fruit freshness and maturity. The results show a high correlation coefficient of 0.88 between the chlorophyll-based measurements and American Oil Chemists' Society measurements, indicating accurate and reliable real-time monitoring. This fluorescence technique provides a significant improvement in quality control, offering a non-invasive and more efficient way to monitor palm oil quality throughout production.

PALM OIL & CHLOROPHYLL

Palm oil is one of the most widely used vegetable oils in the world, utilized in food items and personal care goods. Originating from the fruit of oil palm trees, palm oil and the quality at which it is produced, heavily depends on the fruits' maturity levels and ripeness. As the palm fruit matures, the chlorophyll level decreases leading to a higher quality oil. Although chlorophyll aids the plant in photosynthesis with its green pigment, it has undesirable effects on hydrogenation, the ability to be bleached, and oxidative degradation in palm oil. Fresh fruit bunches harvested at optimal ripeness produce the best quality oil with an optimal oil extraction rate.[1] By carefully tracking chlorophyll levels, palm oil producers and workers can ensure or closely monitor the oil quality throughout the production cycle. From oil extraction and refining to consumer use, high-quality palm oil can be further optimized for production and processing.

Chlorophyll and fruit maturity monitoring not only impacts the attributes and quality of the palm oil but also has implications for marketability and source sustainability. As one of the more popular oils used worldwide for its resistance to oxidation for longer shelf-life, creating efficient and sustainable production plants is critical. Tropical forests, habitats for endangered species, and clean air are all at risk for new and expanding palm oil plantations. While a global marketplace for palm oil based on environment-friendly and sustainable production is ideal, already established palm oil plantations can benefit from more efficient practices that make use of producing more from the fruit and maintaining high-quality oil results. By incorporating advanced analytical techniques and monitoring strategies, the palm oil industry can enhance both economic and environmental aspects of production.

Figure 1. Edible palm oil extracted from the fruit of oil palm trees.

PROBLEMS AND GOALS

Accurately and precisely detecting and monitoring chlorophyll levels in oil palm fruit can lead to higher oil quality and quantities and more sustainable plantations for palm oil production. By determining the maturity of the fruit with the level of chlorophyll, palm oil producers can adjust when the oil is extracted from the oil palm fruit for better oil quality and higher production quality. This allows for a more efficient process of oil extraction and refinement that benefits both the consumer and producer.

Current methods for determining oil palm fruit maturity, outside of human graders looking at fruit arriving at the production floor, include computer vision, spectroscopy, hyperspectral imaging, and thermal imaging. More recent techniques have implemented Raman, infrared and near-infrared optical sensors, and other varieties of spectroscopy to detect chlorophyll or other photosynthetic pigments while being non-invasive to the sample. Non-invasive techniques are highly desired by palm oil producers to keep the production floor operating without interruption. Most of these methods require a sample to be collected and taken offline to a laboratory for chlorophyll content measurements, and many production lines send samples to other companies for analysis and verification. Not only is this time-consuming, but it can be disruptive to the palm oil refinement process, expensive, and labor-intensive. Human inconsistencies and inaccuracies are also problematic when monitoring ripeness and fruit maturing. A real-time technique for chlorophyll level monitoring is needed that is non-invasive and does not disrupt palm oil production. With a portable design, workers can monitor chlorophyll and fruit maturity and freshness with more accessibility, in real-time, for quality control in palm oil production.

METHOD

Researchers from Singapore and Malaysia have developed an in-line, light-induced chlorophyll fluorescence (LICF) probe for non-invasive and real-time monitoring of chlorophyll levels in diluted crude oil. The system integrates a high-intensity LED, photodiode, and a custom bifurcated fiber-optic probe to assess chlorophyll concentrations during the milling process. The LICF setup of the experiment, including the optical probe, LED, and diluted crude palm oil (DCO), is seen in **Figure 2**.

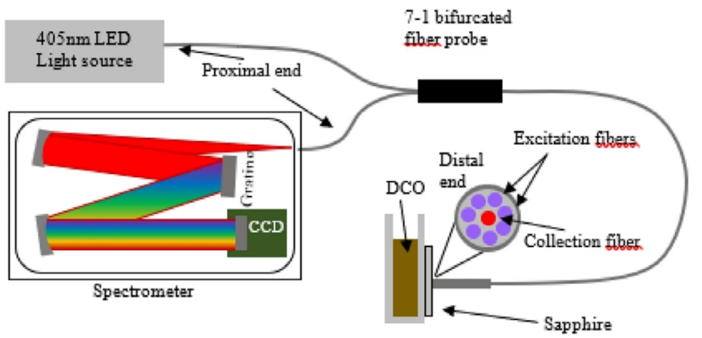

Figure 2. Schematic diagram of LICF setup used in the laboratory for the LICF experiment.[1]

The LED, with a wavelength of 405 nm, was used to excite the oil and produce chlorophyll absorption peaks in the region of 665 nm. Although laser diodes are typically used for absorption spectroscopy, the LED was chosen for its low cost and long lifespan. This LED was driven with constant current with one of Wavelength Electronics' laser diode drivers.

For excitation light delivery and fluorescence collection, a bifurcation fiber probe is used with a 7-1 ratio of delivery fibers to collection fibers. Seven fibers deliver the light to the oil sample, while one center fiber collects the chlorophyll fluorescence and feeds it into the spectrometer for analysis. The linear array CMOS detector in the LICF setup detected variations in light intensity corresponding to chlorophyll concentration. These concentrations, with previously known values, were sent to the American Oil Chemists' Society (AOCS) for validation. With these measurements, a correlation between chlorophyll levels and chlorophyll fluorescence spectra can be made. This proportional relationship is seen in **Figure 3**.

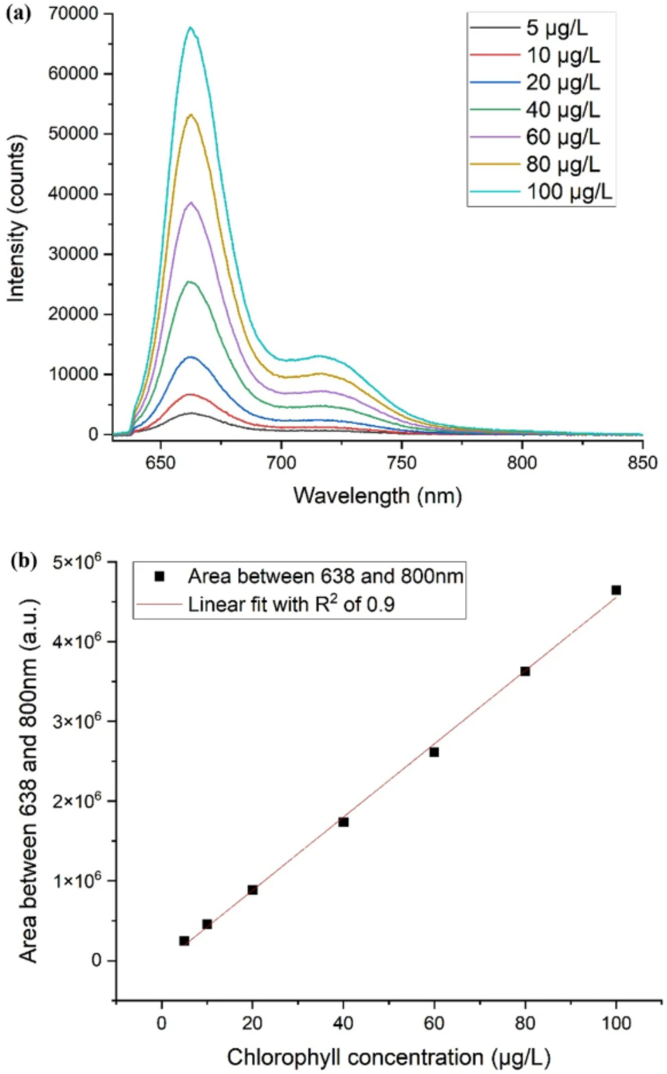

Figure 3. Shows the light-induced chlorophyll fluorescence spectra when excited with a 405 nm LED. (a) The LICF spectra of various chlorophyll concentrations in methanol. (b) The plot shows the linear relationship between chlorophyll fluorescence (fluorescence area) and chlorophyll concentration.[1]

Once the LICF system was validated and calibrated with known concentrations of chlorophyll in palm oil samples, operational testing began. Palm oil samples were introduced into a transparent flow cell where the sensing system continuously monitored chlorophyll levels. To keep the main DCO pipe uninterrupted, a secondary pipe was installed with this transparent flow cell. The system demonstrates the capability to provide real-time feedback on oil quality by correlating chlorophyll concentration with fruit maturity. The monitoring location in **Figure 4** also tested the system's ability to excite the chlorophyll and collect data even with extra fibers from the fruit and soil obstructing the light distribution and absorption.

Samples used for the LICF probe were split into two portions: one stayed at the palm oil mill for chlorophyll measurements, and the other portion was sent to the AOCS for validation. The measurement accuracy was validated by comparing sensor data with the AOCS laboratory analyses of oil samples. The system was able to detect chlorophyll concentration variations with high precision, confirming its reliability for real-time quality monitoring. All results were averaged over multiple measurements to enhance the signal-to-noise ratio and ensure data consistency.

RESULTS

The results revealed a significant correlation between chlorophyll photo-response and key quality indicators. For instance, a decrease in chlorophyll concentration was observed in palm oil with a longer wait time after pollination, a more mature fruit. The system effectively provided real-time alerts for deviations in quality parameters, allowing for timely adjustments in the milling process.

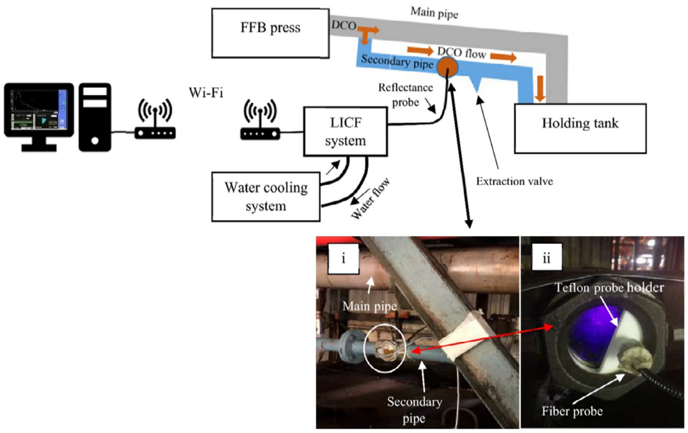

Figure 4. Flow chart of oil palm fresh fruit bunches (FFB) processing at palm oil mills and in-line Chlorophyll LICF prototype setup implemented at dilution & oil classification point in Malaysia. (i) The DCO, after pulp pressing, will flow through the main pipe to the holding tank. A secondary pipe is installed under the main pipe for the installation of the LICF probe. (ii) LICF probe being held by a Teflon probe holder. The probe is separated from the DCO via a sapphire window. The Teflon probe holder is designed to have an opening to enable visual inspection of DCO flow.[1]

With the light-induced chlorophyll fluorescence design, researchers were able to leverage the natural response of chlorophyll to assess the quality of the palm oil. Measurements were analyzed for fruit collected at different weeks after pollination for real-time, non-invasive monitoring of the palm oil quality before refinement in **Figure 5**.

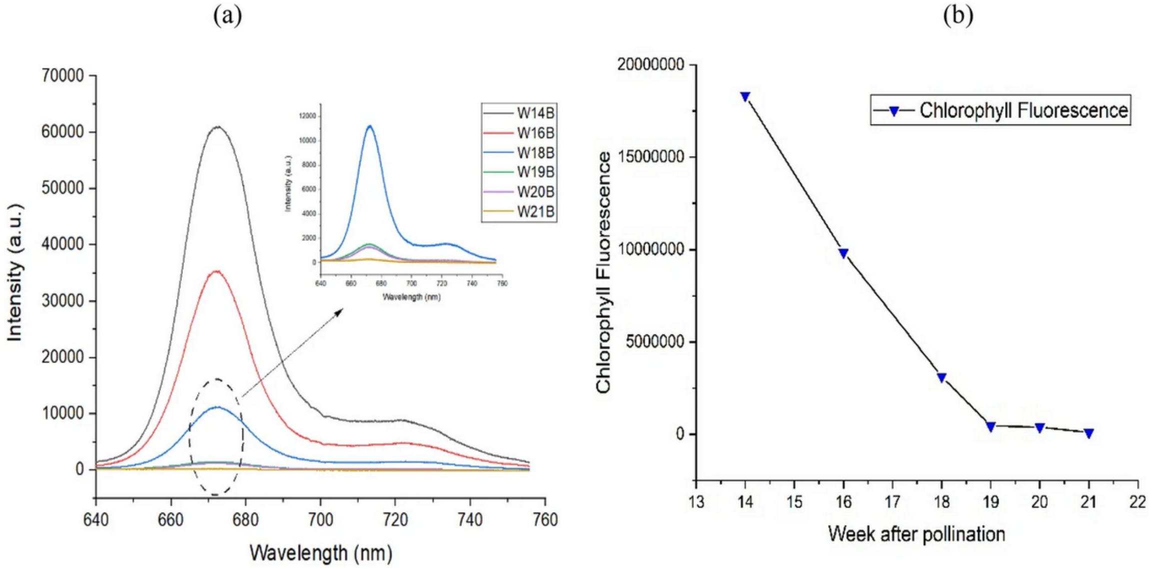

Figure 5. (a) LICF chlorophyll fluorescence spectra of CPO of FFB from different weeks after pollination. (b) Fluorescence area plot vs weeks after pollination.[1]

Real-time monitoring data, shown in **Figure 6**, demonstrated that the system effectively provided feedback on palm oil quality. The system's ability to detect changes in chlorophyll concentration allowed for timely adjustments to the milling process, enhancing process efficiency and quality control. Real-time monitoring also provided instant feedback on flow parameters, mill operation timings, hot water flushing, and the rapidly changing oil quality.

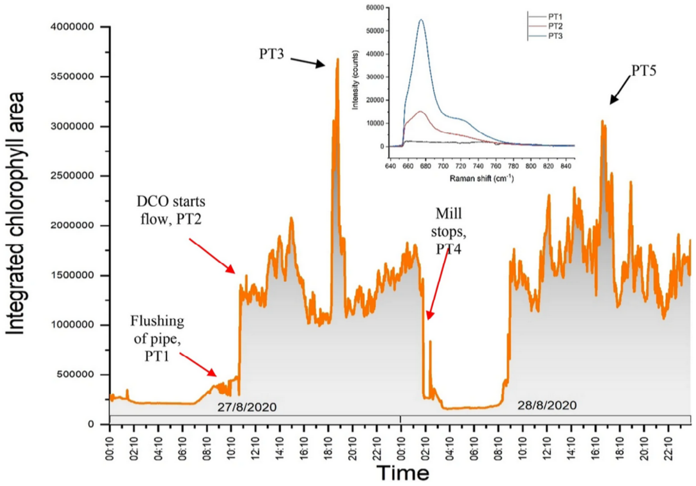

Figure 6. LICF operational plot for 2 days of mill run. PT1, PT2, and PT4 indicate the point in time of hot water pipeline flushing, DCO flows, and end-of-mill operation, respectively. PT3 highlights the point when a high chlorophyll level is being observed. Inset graph plots out the chlorophyll fluorescence at PT1, PT2, and PT3.[1]

Samples of DCO were collected and measured for chlorophyll levels and compared with AOCS measurements. Although these samples are not real-time, there was still a very strong correlation coefficient of 0.90 between the LICF's measurements and AOCS results. **Figure 7** shows the real-time, in-line palm oil mill samples comparison between the LICF prototype's signal and the AOCS data measured in the laboratory. The correlation between the chlorophyll sensor measurements and AOCS results was still very strong, with a correlation coefficient of 0.88.[1] This high accuracy confirms the effectiveness of the in-line sensing system for real-time monitoring of palm oil quality. With the LICF design communicating with a computer in the mill, approximately 1320 spectra can be collected per day, allowing production line workers to adjust the palm fruit used based on maturity levels from chlorophyll measurements.

Multiple tests across different stages of the milling process showed consistent results, indicating that the system is well-suited for continuous quality assessment. The average chlorophyll concentration changes were observable with varying quality indicators, demonstrating the system's capability to adapt to different process conditions.

Overall, the developed LICF system provides a reliable and efficient method for real-time, non-invasive monitoring of palm oil quality. The accuracy and repeatability of chlorophyll measurements and the system's integration into the milling process offer significant improvements in quality control and process optimization for palm oil processing or other applications where chlorophyll can be measured.

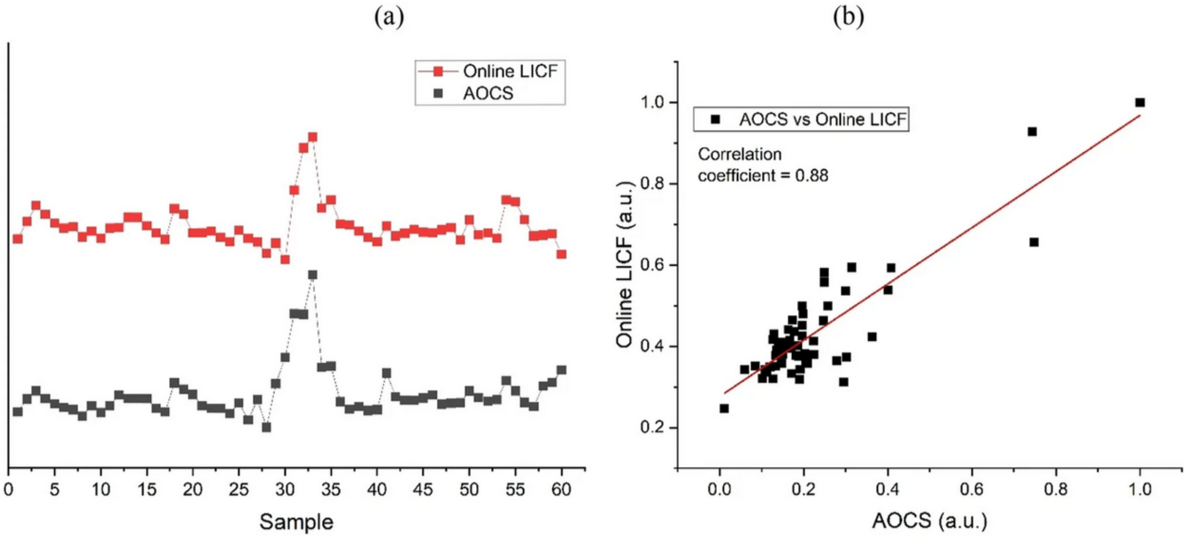

Figure 7. Comparison between the online LICF signal and the AOCS data. The LICF readings were recorded on the spot in the mill. (a) The DCO samples were also collected on the spot for AOCS measurement in the laboratory. (b) The correlation coefficient between the two measurements is 0.88.[1]

WAVELENGTH'S ROLE

In the development of the chlorophyll detection system for palm oil quality monitoring, Wavelength Electronics provided critical components that ensured the stability and accuracy of the system's optical measurements. The precise control of light emission and constant current was essential for detecting chlorophyll photo-response effectively.

Researchers utilized the WLD33ND Laser Driver from Wavelength Electronics to manage the drive current of the LED light source. This driver delivers up to 2.2 A of current with high stability and can operate efficiently with a single +5 V supply. Its compact size, current stability, and as low as zero leakage current were crucial for maintaining stable and consistent light emission, which is vital for accurate chlorophyll measurements. As LEDs are very sensitive to drive current and voltage fluctuations, the WLD33ND driver reduces variation in supplying power to the LED light source.

Additionally, the WLD33ND-2AEV Evaluation Board for the WLD33ND Driver facilitated rapid prototyping and integration of the LED and its driver into the oil monitoring system. The evaluation board simplified the setup process with onboard switches, connectors, and trimpots, making it easy to configure and test the system. This streamlined integration was important for optimizing the LED modulation parameters and ensuring reliable performance during real-time monitoring.

Wavelength Electronics' components played a pivotal role in achieving the necessary precision and stability for the in-line sensing system, demonstrating the importance of fully-featured controllers, engineering expertise, and responsive tech support for high-tech researchers and manufacturers in a wide variety of applications.

PRODUCTS USED
WLD33ND, WLD33ND-2AEV

KEYWORDS
Chlorophyll, palm oil, in-line, real-time, non-invasive, LED, fluorescence, spectroscopy, laser driver, WLD33ND, WLD33ND-2AEV, evaluation board, light-induced chlorophyll fluorescence, LICF, quality, fruit maturity

REFERENCES

1. Tan, E.K.M., Tiong, S.H., Adan, D. et al. Enabling chlorophyll photo-response for in-line real-time noninvasive direct probing of the quality of palm-oil during mill process. *Sci Rep* **13**, 5744 (2023). **https://doi.org/10.1038/s41598-023-32479-7**

USEFUL LINKS

- WLD33ND **Product Page**
- WLD33ND-2AEV **Product Page**

PERMISSIONS

Figures 2 - 7 in this case study were obtained from Reference 1. The article (Ref. 1) is distributed under terms of Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided that you give appropriate credit to the original authors and the source, provide a link to the Creative Commons license, and indicate if changes were made.

Figure 4 was cropped and the caption was adapted. No changes were made to the other captions or images. They are presented here in their original form

REVISION HISTORY

Document Number: CS-LD12

REVISION	DATE	NOTES
A	September 2024	Initial Release