

Portable Vis–NIR Spectroscopy Using AS7265X for Detecting Carbide-Ripened Cavendish Bananas

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ABSTRACT

*Cavendish banana (*Musa acuminata* Cavendish) is one of the horticultural crops whose ripening is often accelerated using calcium carbide (CaC_2), which is harmful to health, thus requiring a scientific method to distinguish natural and artificial ripening. This study aimed to examine the potential of Visible–Near Infrared (Vis-NIR) spectroscopy using the AS7265X multispectral sensor; operating at 410–940 nm, which is portable and more affordable than a laboratory spectrophotometer. A total of 120 samples were used, consisting of 90 unripe (stage 2) and 30 naturally ripened (stage 6) bananas. Linear Discriminant Analysis (LDA) was employed to classify the spectral data, achieving a classification accuracy of 100%. The Vis-NIR spectral patterns showed apparent differences among treatments. Unripe bananas had high reflectance in the blue–green region, while tree-ripened bananas showed increased reflectance in the red and NIR regions. The 64 g/kg carbide treatment yielded a spectral pattern resembling natural ripening, whereas the single lump carbide treatment showed lower reflectance values across most wavelengths. These findings confirmed the potential of the AS7265X sensor to efficiently and non-destructively distinguish between natural and artificial ripening. Practically, this suggests that low-cost, portable sensors can be effectively deployed for real-time field inspection and quality control within the fruit supply chain. Future study need to validate the method using larger and independent datasets.*

1. INTRODUCTION

Banana is one of the most popular horticultural crops among Indonesians. According to data from the Central Bureau of Statistics (BPS), banana production in Indonesia has increased steadily over the past three years. A total of 8,741,147 tons of bananas were produced in 2021, which increased to 9,245,427 tons in 2022, and continued to rise to 9,335,232 tons in 2023 (BPS, 2024). Cavendish banana is one of the banana varieties with high production levels and consumer demand. Bananas are well known as an essential source of energy with high nutritional value, such as protein, potassium, carbohydrates, and vitamins, as well as their sweet taste.

The nutritional content, taste, aroma, and physical appearance of bananas are influenced by fruit ripening. The ripening of bananas occurs rapidly due to an increase in the respiration rate, which is why bananas are categorized as climacteric fruits. As climacteric fruits, bananas naturally ripen after harvest and during storage within approximately 4–5 days (Zainul, 2020). The need to store bananas for several days to achieve the desired ripening is a disadvantage of natural ripening, as it takes a long time. In addition, natural ripening produces non-uniform colors, so chemical compounds are needed to accelerate and equalize the ripening process.

Several chemical-induced ripening methods include the application of ethylene gas, calcium carbide (CaC_2), ethephon or ethrel (2-chloroethyl phosphonic acid), ethylene glycol, and methyl jasmonate (MeJA). The chemical

compound most widely used for banana ripening in Indonesia is calcium carbide, as it is readily available on the market and relatively inexpensive compared to other chemicals. Calcium carbide (CaC_2) positively influences unripe bananas by inducing color change and extending shelf life (Bafor *et al.*, 2019). However, calcium carbide also has harmful effects on human health when consumed continuously, including discomfort in the mouth and nose, difficulty swallowing, persistent thirst, headache, and fatigue, long-term skin damage, skin ulcers, and kidney failure (Okeke *et al.*, 2022).

Although calcium carbide used for banana ripening has adverse effects, some people in Indonesia still use it due to market demand. Research by Islam *et al.* (2016) revealed that there are no specific regulations in Indonesia regarding the proper dosage of calcium carbide for artificial banana ripening. In other countries, the use of carbide in banana ripening, according to Nuhu *et al.* (2020), is assessed by phosphorus and arsenic content in bananas that are safe for consumption based on the standards of the Food and Agriculture Organisation (FAO), which are 0.5–2 mg/kg and 80–120 mg/kg, respectively. Even though there are safe limits for the use of calcium carbide, continuous consumption of such bananas can still pose a risk to human health.

Indonesian consumers generally have limited knowledge of artificially ripened bananas produced with calcium carbide compared to naturally ripened ones. This lack of awareness makes it difficult for people to distinguish naturally ripened bananas from artificially ripened ones because of their similar colour. One method to differentiate natural and artificial banana ripening without damaging the product is spectroscopy.

While machine vision based on simple colour imaging is effective for assessing external appearance, it is fundamentally limited to surface features. This limitation is critical when detecting calcium carbide-induced ripening, which frequently causes a deceptive rapid degreening of the peel while the pulp remains physiologically unripe (Zaukuu *et al.*, 2024). Spectroscopy overcomes this by analysing the interaction of light with internal tissue structures, allowing for the detection of specific biochemical discrepancies, such as moisture content and starch hydrolysis, that surface-level color analysis simply cannot resolve.

Spectroscopy is an accurate, reliable, and efficient alternative method for non-destructive evaluation of agricultural product quality. According to Hasanzadeh *et al.* (2022), the potential use of spectroscopy has been increasing in various fields, especially in food. One application is visible-near-infrared (Vis-NIR) spectroscopy for analysing fresh produce in postharvest processes, combining the visible spectrum (400–750 nm) and the near-infrared spectrum (750–2500 nm) (Walsh *et al.*, 2020). However, despite the increasing use of low-cost multispectral sensors, their application for distinguishing carbide-induced ripening in bananas remains limited.

Previous research has identified differences between naturally ripened and carbide-ripened mangoes using fluorescence spectroscopy with a microspectrometer by Wahyudi & Harsono (2023). The results of that study showed that the average chlorophyll fluorescence (ChlF) spectrum peaks could distinguish between naturally and artificially ripened mangoes. Therefore, the objective of this research was to investigate the application of Vis-NIR spectroscopy using the AS7265X spectroscopic sensor, which detects spectra in the 410–940 nm range and has not yet been applied to distinguish between naturally ripened and carbide-ripened bananas.

2. MATERIALS AND METHODS

The research was conducted from February to July 2025. The system design and implementation were carried out at the Laboratory of Food and Agricultural Product Processing Engineering (LTPPHP) in the Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Andalas University. This study used an experimental method in which bananas were exposed to visible and near-infrared light from the AS7265X spectroscopy sensor, and the reflected light was measured to obtain spectral patterns over 410–940 nm.

The tools used in this research were the Sparkfun Triad Spectroscopy Sensor AS7265X, an ESP32 microcontroller, a laptop, a breadboard, a USB cable, jumper wires, fabric scraps, and plain cardboard boxes (22×15×10 cm), totaling 60 boxes for storing ripened banana using carbides. The samples required for this study were 90 bananas at ripening stage 2 (ripe at the tree) and 30 at ripening stage 6 (ripened using carbide). The total amount of carbide used for banana ripening was approximately ±540 grams.

2.1. Calibration of the AS7265X Sensor with a Vis-NIR Spectrophotometer

The research began with calibration of the AS7265X sensor using a spectrophotometer at the Biophysics Laboratory, Faculty of Agricultural Technology, Gadjah Mada University, Yogyakarta, to ensure accuracy of spectral readings. Calibration was performed by comparing the reflectance values derived from the AS7265X sensor (normalized using a white reference standard) with the reflectance measured using the Flame-T-VIS-NIR spectrophotometer. The normalization process was adapted from [Nguyen *et al.* \(2020\)](#); specifically, the relative response was calculated by dividing the sample signal by the white reference signal to ensure data consistency and eliminate bias. Measurement conditions were maintained by matching the positions, distances, and angles of both devices relative to the sample, and all measurements were conducted in a dark room to avoid external light interference.

Calibration of this process was purposed to demonstrate that the portable sensor successfully reproduced the characteristic spectral signatures of the samples, including key absorption features in the visible region and the sharp reflectance rise in the near-infrared (NIR) transition. Although the AS7265X recorded slightly lower absolute reflectance values, this is an inherent characteristic attributed to the sensor's technical specifications, specifically its wider Full Width at Half Maximum (FWHM) of 20 nm. This wider bandwidth means the sensor averages the light intensity over a larger range, producing a spectral curve that faithfully follows the pattern of the high-precision laboratory instrument. Consequently, as the relative spectral trends remained highly consistent between both devices, the calibration process conclusively validated the sensor's precision, establishing it as a reliable instrument for the non-destructive data acquisition in this study.

2.2. Assembly of the Spectral Measurement Device

The spectral measurement setup in Figure 1 consisted of several components: a Sparkfun Triad Spectroscopy Sensor AS7265X, an ESP32 microcontroller, a breadboard, jumper wires, a laptop, black cardboard, and a USB cable. To establish data communication, the AS7265X sensor was interfaced with the ESP32 microcontroller using the Inter-integrated circuit (I2C) protocol; specifically, the sensor's serial clock (SCL) and serial data (SDA) pins were connected to GPIO 22 and GPIO 21 on the ESP32, respectively, while power was supplied via the 3.3V and GND connections. The Sparkfun Triad Spectroscopy Sensor AS7265X as a multispectral sensor, was capable of detecting light from the visible to NIR range (410–940 nm). The AS7265X sensor operated using the reflectance method, in which light was reflected from the fruit surface, and the reflected intensity was measured as reflected irradiance at 18 wavelengths in the Vis-NIR region. The reflected irradiance data, in the form of spectra, were read by the ESP32 microcontroller, which then processed the data. The microcontroller was connected to the laptop via a USB cable to display measurement results with a custom program.



Figure 1. The AS7265X-based spectral data acquisition system

2.3. Preparation of Research Materials

The research materials were Cavendish bananas subjected to different treatments, including ripening with carbide at varying doses. Cavendish bananas were obtained from farmers' plantations in Pariaman. Thirty bananas at ripening stage six were harvested directly from the tree, while ninety bananas at ripening stage two were also harvested. After harvesting, the bananas were wrapped in cardboard boxes for transport to the Laboratory of Food and Agricultural Product Processing Engineering, Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Andalas University, Padang. The bananas were then sorted and graded as Class A Cavendish bananas under SNI No. 01-6946-2003, with finger lengths ranging from 17–20 cm and bunch weights exceeding 3 kg.

The amount of carbide used for each banana was adjusted based on the weight of bananas (g), multiplied by 0.064 g of carbide (equivalent to 64 g/kg banana). Meanwhile, some bananas were ripened with a single small piece of carbide without a specific weight to observe ripening without a fixed dose. Calcium carbide was applied using two distinct treatments to induce ripening. Specifically, 30 banana samples were treated with a concentration of 64 g/kg, and 30 samples were treated with a single solid lump of carbide. For each treatment, the carbide was wrapped in cloth and sprinkled with a small amount of water to release acetylene gas (Mubarak *et al.*, 2021). The ripening chambers consisted of 60 plain cardboard boxes (22×15×10 cm), corresponding to the total number of samples that ripened with carbide. The box dimensions were selected to accommodate the average length (17–20 cm) and diameter (3.5–4 cm) of the Cavendish bananas. Each banana was placed in the center of the box, with the carbide positioned at the base. The boxes were tightly sealed for a duration of 72 hours to ensure consistent gas exposure.

2.4. Measurement Procedure

Bananas were measured using the multispectral AS7265X sensor, which detects irradiance across visible to near-infrared wavelengths (410–940 nm). Visible to near-infrared light from the sensor was projected onto the banana peel; the tissue absorbed part of the light, and the remainder was reflected, with the reflected light read by the sensor and converted into digital spectral data (Wang *et al.*, 2023). All procedures were conducted in a dark room to prevent external light from interfering with the sensor readings (Tran & Fukuzawa, 2020). To establish a reliable baseline for spectral comparison, a white reference standard was employed to normalize the sensor output before scanning the samples. The bananas were positioned perpendicular to the sensor at a distance of less than 1 cm. To ensure the data represented the entire fruit, spectral acquisition was performed on two distinct areas of each sample, specifically the upper and lower surfaces. The readings from these dual scans were subsequently averaged to generate a single mean spectral signature for every banana. The monitoring timeline consisted of two critical phases: a baseline measurement recorded for all samples in their unripe condition prior to treatment application, followed by a final assessment conducted immediately upon the conclusion of the 72 h ripening duration. The assessment was strictly limited to 72 h to prevent over-ripening and tissue necrosis, which induce enzymatic browning. Such physical darkening significantly alters light absorption, leading to unstable reflectance values that would represent tissue decay rather than the intended ripening process. All samples were measured, and the results were analyzed to identify differences between bananas ripened with calcium carbide and those tree-ripened.

3. RESULTS AND DISCUSSION

Spectral reflectance analysis of bananas was performed using the AS7265X sensor operates in the visible-to-near-infrared (Vis-NIR) wavelength range of 410–940 nm. The visible region focused on colour assessment and pigment analysis, while the NIR region corresponded to O–H and C–H bond vibrations commonly found in fruit tissues (Walsh *et al.*, 2020). Reflected spectra from bananas showed physiological changes, including ripening, water content, and chlorophyll degradation, which can be observed as directional patterns in the spectra (Solovchenko *et al.*, 2010).

Pigments and other absorbing compounds influenced the Vis-NIR spectra reflected from banana peels. Pigments such as chlorophyll, carotene, and xanthophyll dominated responses in the visible region, determining fruit colour and serving as visual indicators of ripening (Walsh *et al.*, 2020). Meanwhile, responses in the NIR region were affected by water and organic compounds through molecular vibrational absorption, making it useful for non-destructive assessment of internal quality (Wang *et al.*, 2022).

The spectral reflectance of unripe Cavendish bananas is shown in Figure 2. The graph indicates spectral patterns typical of the early physiological stage. Reflectance values were relatively low in the 410–485 nm range, then increased at 510–610 nm. This pattern aligns with [Ringer & Blanke \(2021\)](#), who reported a decrease in reflectance at 450–500 nm, followed by an increase up to 600 nm. The decrease in reflectance at 610–645 nm was also consistent with [Ringer & Blanke \(2021\)](#), who showed low reflectance in the 600–650 nm range. Reflectance increased again at 645–860 nm, in agreement with [Chu *et al.* \(2022\)](#), who observed a minimum reflectance around 670 nm followed by a gradual increase toward 860 nm. A decline in reflectance was observed in the 860–940 nm range, consistent with [Chu *et al.* \(2022\)](#), who reported that reflectance peaked near 860 nm before decreasing at longer wavelengths.

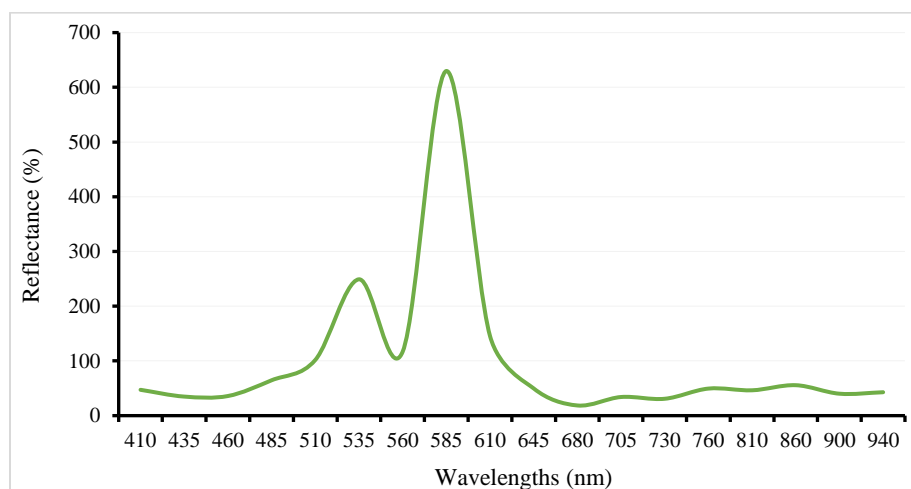


Figure 2. Spectral reflectance of unripe Cavendish banana

Based on the reflectance spectrum of unripe Cavendish bananas (ripening stage two), three reflectance peaks were identified at 535 nm and 585 nm. The reflectance peak at 535 nm reached 249%, indicating the dominant reflection of green light by active chlorophyll in green banana tissues. [Nguyen *et al.* \(2022\)](#) explained that chlorophyll a and b still dominated fruit tissue structure, resulting in low absorption and strong reflection of green light around 525 nm.

The relatively low reflectance values at 410–485 nm were due to strong absorption of blue light (400–500 nm) by chlorophyll a and b. In contrast, reflectance at 510–535 nm was higher due to green light reflected by chlorophyll pigments in the 500–565 nm range. This finding supports [Liu & van Iersel \(2021\)](#), who stated that chlorophyll a and b absorb blue light more strongly and reflect green light, resulting in lower reflectance in the blue region compared to the green region.

Reflectance increased in the 560–610 nm range, indicating higher reflectance due to low anthocyanin levels. [Pratiwi *et al.* \(2023\)](#) reported that bananas exhibit high reflectance at 550–600 nm because of lack anthocyanins, pigments responsible for red, purple, and blue colors in fruits such as dragon fruit. In contrast, the reflectance dip at 645 nm reflected strong absorption of red light by chlorophyll. [Trang *et al.* \(2019\)](#) confirmed that chlorophyll *a* absorbs red radiation maximally around 650 nm, so a high chlorophyll concentration leads to low reflectance in this region.

Beyond 680 nm, the reflectance spectrum remained consistently low throughout the near-infrared (NIR) region. [Kasampalis *et al.* \(2025\)](#) reported that suppressed reflectance in the 680–720 nm range is significantly correlated with low soluble solid content. Similarly, [Liew & Lau \(2012\)](#) noted that unripe bananas possess high firmness and low sugar levels, resulting in strong light absorption and consequently low reflectance values in this band. Although a minor elevation was observed peaking at 860 nm, the overall intensity remained low compared to the visible region. [Nguyen *et al.* \(2020\)](#) associated spectral features in this range with the organic acid content characteristic of early ripening stages. Finally, a slight decline was recorded at 900 and 940 nm, indicating water absorption (O–H vibrational modes) within the starch-rich tissue, as described by [Wang *et al.* \(2020\)](#).

The spectral reflectance of tree-ripened Cavendish bananas at ripening stage six is shown in Figure 3. In the visible region, reflectance values are generally low, reflecting strong absorption by residual chlorophyll in the blue-green range (400 to 565 nm) and increased reflection from carotenoids and xanthophylls in the yellow-red range (565 to 700 nm). Huang *et al.* (2024) explained that ripening involves chlorophyll degradation and carotenoid accumulation, which alter the peel's light-reflectance pattern. In the NIR region, reflectance at 860 nm indicating reflection from soft tissue. Huang *et al.* (2024) also stated that fruit softening is influenced by starch degradation into glucose and fructose, which alters tissue structure and light scattering. The increase in glucose and fructose contributes additional O–H and C–H groups, which are strongly detected in the NIR region above 700 nm (Omar *et al.*, 2012). This is consistent with Wang *et al.* (2020), who identified O–H and C–H absorption peaks at 876 nm and 967 nm, respectively. This suggests that spectral reflectance in the NIR region is strongly associated with internal biochemical transformations rather than surface color changes.

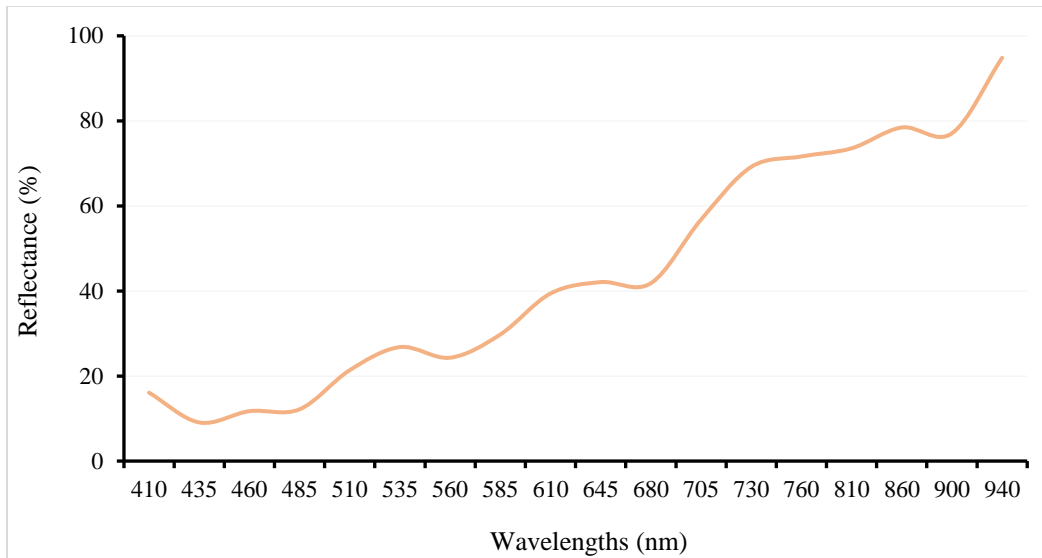


Figure 3. Spectral reflectance of tree-ripened Cavendish banana

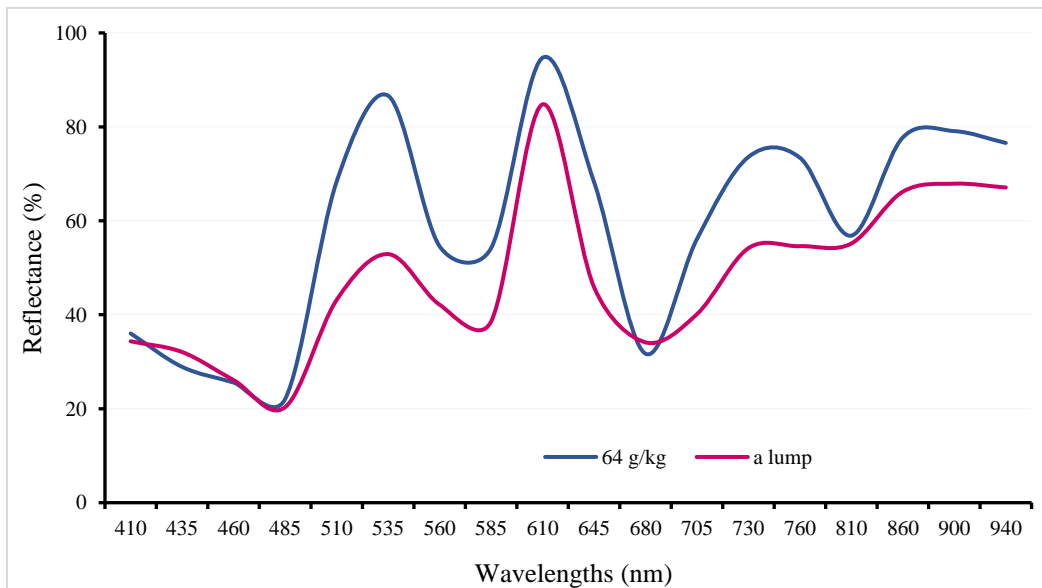


Figure 4. Spectral reflectance of Cavendish bananas ripened using calcium carbide

The spectral reflectance of Cavendish bananas ripened with calcium carbide a dose of 64 g/kg and with one lump is presented in Figure 4. The spectra of chemically ripened bananas show a general pattern resembling ripe fruit, with fluctuating curves in the visible region and a sharp increase in the NIR region.

Reflectance values vary with the applied dose. The highest reflectance was recorded at 64 g/kg carbide-ripened banana, while the lowest was observed with the one-lump treatment. This indicates that higher doses accelerate ripening and tissue softening, reflected in stronger reflectance in the NIR region. Roy *et al.* (2021) reported that carbide-induced ripening accelerates chlorophyll degradation and green colour loss, although starch hydrolysis may remain incomplete.

In the visible region, bananas ripened with 64 g/kg showed higher irradiance than those ripened with one lump, indicating faster peel colour change. By contrast, the one lump treatment produced the lowest reflectance in the visible range, indicating partial ripening. This aligns with Maduwanthi & Marapana (2019), who found that very low acetylene concentrations fail to trigger optimal yellow colouration. The 64 g/kg treatment promoted significant tissue softening without major loss of fruit quality, consistent with structural carbohydrate degradation into simple sugars as described by Nuhu *et al.* (2020). In contrast, the one lump treatment produced suboptimal ripening because the generated acetylene gas was insufficient (Asif, 2012).

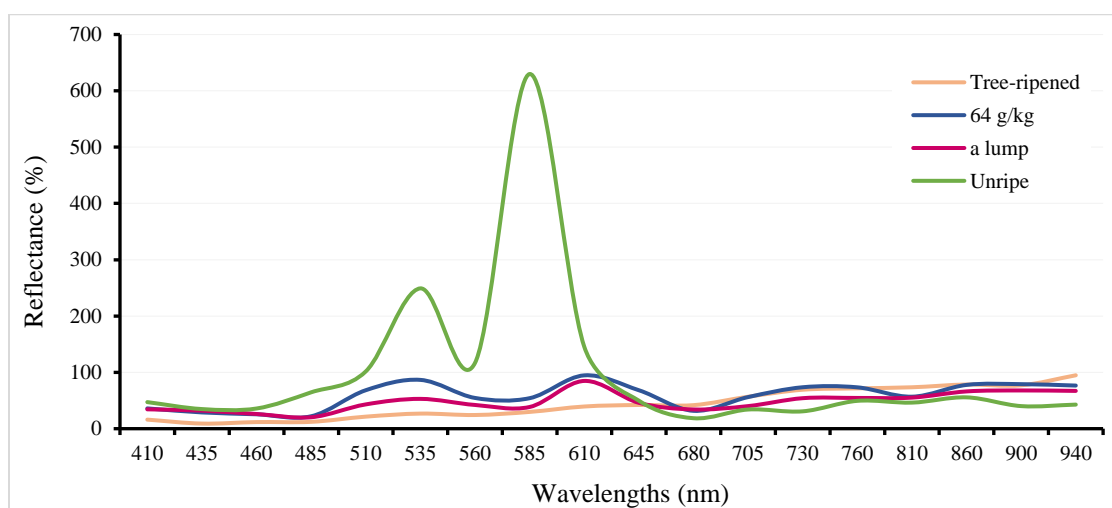


Figure 5. Spectral reflectance of Cavendish bananas under all treatments

A comparison of Cavendish bananas across all treatments, including raw, tree-ripened, 64 g/kg carbide, and one lump, is presented in Figure 5. Unripe bananas exhibited the highest reflectance values across most of the visible range, with two main peaks at 535 nm and 585 nm, corresponding to high chlorophyll content and firm texture. Tree-ripened bananas showed lower reflectance in the visible region but continue to increase in the NIR region, reflecting full ripening with softened tissue and higher water content. This trend matches the climacteric ripening phase described by Zhang *et al.* (2014).

Bananas ripened with 64 g/kg carbide showed spectra between those of tree-ripened and unripe bananas. In the visible region, reflectance was relatively high, indicating a significant change in peel colour. In contrast, in the NIR region, particularly at 860 nm, the reflectance resembled tree-ripened bananas rather than unripe fruit. This suggests that the 64 g/kg dose promotes more balanced ripening, both in external appearance and internal structure.

In contrast, bananas treated with one lump of carbide showed the lowest reflectance across almost all wavelengths, indicating partial ripening due to limited acetylene exposure. This is consistent with Maduwanthi & Marapana (2019), who found that very low acetylene concentrations are insufficient to induce full yellow colouration. Zaukuu *et al.* (2024) also noted that low-dose carbide treatment tends to increase titratable acidity, reflecting limited metabolic activity during ripening.

The classification of banana samples based on ripeness stages and ripening methods was analyzed using Linear Discriminant Analysis (LDA) derived from the spectral data captured by the AS7265X spectroscopy sensor. The spatial distribution of the data points across the two primary canonical variables is presented in Figure 6. The LDA score plot demonstrates a clear and distinct separation between the four treatment groups which consist of unripe, tree ripened, artificially ripened with 64 g/kg carbide and a lump of carbide. The first canonical variable accounts for the primary variance in the dataset and effectively distinguishes between the physiological phases of the fruit. The unripe samples formed a tight cluster in the positive region of the first variable while all ripe samples were distributed in the negative region regardless of the ripening process. This separation indicates that the AS7265X sensor is highly capable of detecting the spectral shifts associated with the pigment and physicochemical changes that occur during the transition from the unripe to the ripe stage.

The second canonical variable provided critical discrimination between the ripening agents. Tree ripened bananas were clustered in the negative region of the second variable whereas both carbides treated groups were located in the positive region. This suggests that artificially ripened bananas possess a distinct spectral signature compared to those ripened naturally on the tree. The analysis also shows a clear boundary within the artificial category where the 64 g/kg and the single lump treatments formed separate clusters. This indicates that the AS7265X spectroscopy system provides sufficient resolution to differentiate varying concentrations and application methods of calcium carbide likely due to subtle differences in skin coloration or surface reflectance induced by the rapid chemical ripening process.

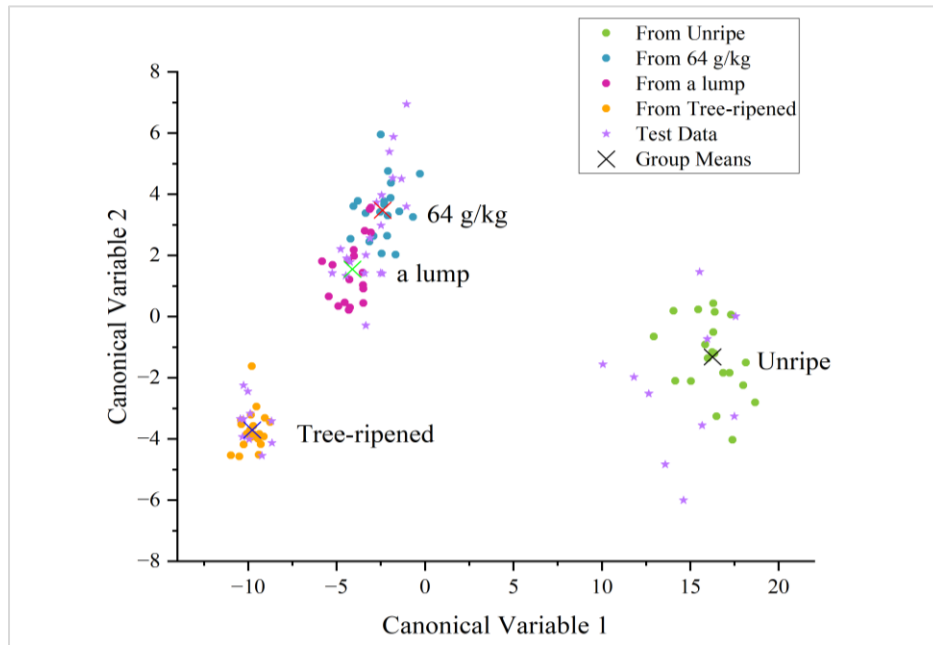


Figure 6. Linear discriminant analysis of Cavendish bananas under all treatments

The reliability of the LDA model based on the AS7265X spectral data was validated using a prediction dataset as shown in the confusion matrix in Figure 7. The model was evaluated using 40 banana samples with an equal distribution of 10 samples for each of the four categories. The classification model achieved a recognition accuracy of 100% where all samples were correctly assigned to their respective classes. The system successfully predicted all 10 samples for the unripe group, the tree ripened group, the 64 g/kg carbide group, and the single lump carbide group without any errors. The absence of errors in the off-diagonal cells confirms that there were no misclassifications between the natural and artificial ripening methods. This perfect discrimination demonstrates that the developed method using the AS7265X sensor yields high precision in identifying the ripeness level of bananas and distinguishing the specific ripening treatment applied. Although the model achieved 100% accuracy, this result may indicate potential overfitting due to the limited dataset size. Further validation using larger and independent datasets is required.

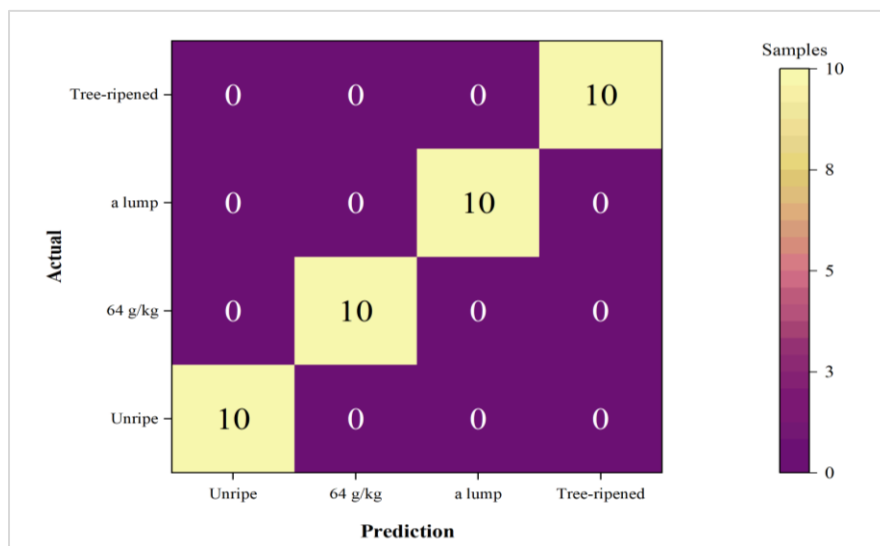


Figure 7. Confusion matrix of the classification results

4. CONCLUSIONS

This study demonstrated the effectiveness of the portable AS7265X multispectral sensor in differentiating between naturally and artificially ripened Cavendish bananas. Spectral analysis revealed distinct reflectance patterns, where unripe bananas exhibited dominant peaks in the visible blue–green region, while tree-ripened bananas showed characteristic features in the red and near-infrared (NIR) regions. Validating these observations, the Linear Discriminant Analysis (LDA) model achieved a classification accuracy of 100%, confirming that the sensor can statistically distinguish between varying ripening treatments. Furthermore, the sensor successfully detected spectral differences between the 64 g/kg carbide dosage and the single-lump treatment, indicating its sensitivity to different ripening intensities. These results suggest that the developed system offers a viable, low-cost, and non-destructive alternative for fruit quality inspection. This approach has strong potential for practical deployment in food safety monitoring and supply chain inspection. Future studies are recommended to expand the dataset with varying carbide dosages and exposure durations to test the model's robustness. It is also advisable to correlate spectral reflectance data with quantitative physiological parameters, such as total soluble solids (TSS), firmness, and starch content, to fully understand the internal biochemical changes associated with artificial ripening.

AUTHOR CONTRIBUTION STATEMENT

| Author | C | M | So | Va | Fo | I | R | D | O | E | Vi | Su | P | Fu |
|--------|---|---|----|----|----|---|---|---|---|---|----|----|---|----|
| NL | | ✓ | ✓ | | | ✓ | | | ✓ | | | | | |
| Ifm | ✓ | | | | ✓ | | ✓ | ✓ | | ✓ | | | | ✓ |
| And | | ✓ | | ✓ | | | | | | | ✓ | | | |

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|----------------------|---------------------|-------------------------------|---------------------------|
| C: Conceptualization | Fo: Formal Analysis | O: Writing - Original Draft | Fu: Funding Acquisition |
| M: Methodology | I: Investigation | E: Writing - Review & Editing | P: Project Administration |
| So: Software | D: Data Curation | Vi: Visualization | |
| Va: Validation | R: Resources | Su: Supervision | |

REFERENCES

Asif, M. (2012). Physico-chemical properties and toxic effect of fruit-ripening agent calcium carbide. *Annals of Tropical Medicine and Public Health*, 5(3), 150–156.

BPS (Badan Pusat Statistik). (2024). *Produksi Tanaman Buah-buahan dan Sayuran Tahunan Menurut Jenis Tanaman, 2023* [Statistik tabel]. BPS-Statistics Indonesia, accessed 16 September 2024. <https://www.bps.go.id/en/statistics->

<table/3/WXpSVU5uUTBOSEI5WVhGQmVESTVSVnBSVlhWeVVUMDkjMw==/produksi-buahbuahan-dan-sayuran-tahunan-menurut-jenis-tanaman-2023.htm>

- Bafor, E.E., Greg-Egor, E., Omoruyi, O., Ochoyama, E., & Omogiade, G.U. (2019). Disruptions in the female reproductive system on consumption of calcium carbide ripened fruit in mouse models. *Heliyon*, *5*(9), e02397. <https://doi.org/10.1016/j.heliyon.2019.e02397>
- Chu, X., Miao, P., Zhang, K., Wei, H., Fu, H., Liu, H., Jiang, H., & Ma, Z. (2022). Green banana maturity classification and quality evaluation using hyperspectral imaging. *Agriculture*, *12*(4), 530. <https://doi.org/10.3390/agriculture12040530>
- Hasanzadeh, B., Abbaspour-Gilandeh, Y., Soltani-Nazarloo, A., De La Cruz-Gámez, E., Hernández-Hernández, J.L., & Martínez-Arroyo, M. (2022). Non-destructive measurement of quality parameters of apple fruit by using visible/near-infrared spectroscopy and multivariate regression analysis. *Sustainability*, *14*(22), 14918. <https://doi.org/10.3390/su142214918>
- Huang, P.-H., Cheng, Y.-T., Lu, W.-C., Chiang, P.-Y., Yeh, J.-L., Wang, C.-C., Liang, Y.-S., & Li, P.-H. (2024). Changes in nutrient content and physicochemical properties of Cavendish bananas var. Pei Chiao during ripening. *Horticulturae*, *10*(4), 384. <https://doi.org/10.3390/horticulturae10040384>
- Islam, M.N., Mursalat, M., & Khan, M.S. (2016). A review on the legislative aspect of artificial fruit ripening. *Agriculture & Food Security*, *5*, 8. <https://doi.org/10.1186/s40066-016-0057-5>
- Kasampalis, D.S., Tsouvaltzis, P., & Siomos, A.S. (2025). Assessment of melon fruit nutritional composition using VIS/NIR/SWIR spectroscopy coupled with chemometrics. *Horticulturae*, *11*(6), 658. <https://doi.org/10.3390/horticulturae11060658>
- Liew, C.Y., & Lau, C.Y. (2012). Determination of quality parameters in cavendish banana during ripening by NIR spectroscopy. *International Food Research Journal*, *19*(2), 751–758.
- Liu, J., & van Iersel, M.W. (2021). Photosynthetic physiology of blue, green, and red light: Light intensity effects and underlying mechanisms. *Frontiers in Plant Science*, *12*, 619987. <https://doi.org/10.3389/fpls.2021.619987>
- Maduwanthi, S.D.T., & Marapana, R.A.U.J. (2019). Induced ripening agents and their effect on fruit quality of banana. *International Journal of Food Science*, *2019*, 2520179. <https://doi.org/10.1155/2019/2520179>
- Mubarak, M.Z., Lailiyah, H., Wahyuni, D.P., Aini, M., Rahayu, Y.S., & Dewi, S.K. (2021). Effect of ripening method on banana and pineapple maturation. *Inovasi Riset Biologi dalam Pendidikan dan Pengembangan Sumber Daya Lokal*, 541–55.
- Nasir, U., Ismail, A., Riaz, M., Razzaq, K., Ali, S., Hussain, A., Ameen, M., Saif, A., Aslam, F., & Fernandes de Oliveira, C.A. (2024). Exploring fruit ripening methods: Conventional, artificial, and novel approaches for quality and health. *Food Control*, *165*, 110626. <https://doi.org/10.1016/j.foodcont.2024.110626>
- Nguyen, A.X., Ta Ngoc, M.C., Duong, H.T., Nguyen Thi, M.N., Ha, Q.T., Trinh Tran, H.D., & Tran, T.N. (2023). Using VIS–NIR imaging for non-intrusive *Musa acuminata* banana color changes assessment over a maturity period. *EPiC Series in Engineering*, *5*, 81–90. <https://doi.org/10.29007/tfqx>
- Nguyen, C.-N., Phan, Q.-T., Tran, N.-T., Fukuzawa, M., Nguyen, P.-L., & Nguyen, C.-N. (2020). Precise sweetness grading of mangoes (*Mangifera indica* L.) based on random forest technique with low-cost multispectral sensors. *IEEE Access*, *8*, 212371–212382. <https://doi.org/10.1109/ACCESS.2020.3040062>
- Nuhu, A.M., Rabi, A., & Tukur, H.R. (2020). Proximate and elemental analysis of banana fruits (*Musa* spp.) ripened with various concentrations of calcium carbide. *Journal of Chemical Society of Nigeria*, *45*(4). <https://doi.org/10.46602/jcsn.v45i4.501>
- Okeke, E.S., Okagu, I.U., Okoye, C.O., & Ezeorba, T.P.C. (2022). The use of calcium carbide in food and fruit ripening: Potential mechanisms of toxicity to humans and future prospects. *Toxicology*, *468*, 153112. <https://doi.org/10.1016/j.tox.2022.153112>
- Omar, A.F., Atan, H., & MatJafri, M.Z. (2012). Peak response identification through near-infrared spectroscopy analysis on aqueous sucrose, glucose, and fructose solution. *Spectroscopy Letters*, *45*(3), 190–201. <https://doi.org/10.1080/00387010.2011.604065>
- Pratiwi, E.Z.D., Pahlawan, M.F.R., Rahmi, D.N., Amanah, H.Z., & Masithoh, R.E. (2023). Non-destructive evaluation of soluble solid content in fruits with various skin thicknesses using visible–shortwave near-infrared spectroscopy. *Open Agriculture*, *8*(1), 20220183. <https://doi.org/10.1515/opag-2022-0183>
- Ringer, T., & Blanke, M. (2021). Non-invasive, real time in-situ techniques to determine the ripening stage of banana. *Journal of Food Measurement and Characterization*, *15*, 4426–4437. <https://doi.org/10.1007/s11694-021-01009-2>

- Roy, M., Langthasa, S., & Hazarika, D.N. (2021). Indigenous ripening methods for banana cv. Amritsagar. *Journal of Pharmacognosy and Phytochemistry*, **10**(3), 432–436.
- Solovchenko, A.E., Chivkunova, O.B., Gitelson, A.A., & Merzlyak, M.N. (2010). Non-destructive estimation pigment content ripening quality and damage in apple fruit with spectral reflectance in the visible range. *Fresh Produce*, **4**(Special Issue 1), 91–102.
- Tran, N.-T., & Fukuzawa, M. (2020). A portable spectrometric system for quantitative prediction of the soluble solids content of apples with a pre-calibrated multispectral sensor chipset. *Sensors*, **20**(20), 5883. <https://doi.org/10.3390/s20205883>
- Trang, N.M., Duy, T.K., Huyen, T.T.N., Danh, L.V.Q., & Dinh, A. (2019). An investigation into the use of a low-cost NIR integrated circuit spectrometer to measure chlorophyll content index. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, **8**(7C2).
- Wahyudi, P.P., & Harsono, B. (2023). Identifikasi mangga arumanis yang dimatangkan dengan kalsium karbida (CaC₂) menggunakan metode spektroskopi. *TECHNe: Jurnal Ilmiah Elektroteknika*, **22**(1). <https://doi.org/10.31358/techne.v22i1.368>
- Walsh, K.B., Blasco, J., Zude-Sasse, M., & Sun, X. (2020). Visible-NIR ‘point’ spectroscopy in postharvest fruit and vegetable assessment: The science behind three decades of commercial use. *Postharvest Biology and Technology*, **168**, 111246. <https://doi.org/10.1016/j.postharvbio.2020.111246>
- Wang, M., Wang, B., Zhang, R., Wu, Z., & Xiao, X. (2023). Flexible Vis/NIR wireless sensing system for banana monitoring. *Food Quality and Safety*, **7**, fyad025. <https://doi.org/10.1093/fqsafe/fyad025>
- Wang, M., Xu, Y., Yang, Y., Mu, B., Nikitina, M.A., & Xiao, X. (2022). Vis/NIR optical biosensors applications for fruit monitoring. *Biosensors and Bioelectronics: X*, **II**, 100197. <https://doi.org/10.1016/j.biosx.2022.100197>
- Wang, Z., Erasmus, S.W., Liu, X., & van Ruth, S.M. (2020). Study on the relations between hyperspectral images of bananas (*Musa* spp.) from different countries, their compositional traits and growing conditions. *Sensors*, **20**(20), 5793. <https://doi.org/10.3390/s20205793>
- Zainul, M. (2020). *Profil perubahan sifat enjiniring buah pisang raja (Musa paradisiaca) selama proses pemeraman buatan*. [Undergraduate Thesis], Universitas Jember Digital Repository.
- Zaukuu, J.-L.Z., Mensah, S., Mensah, E.T., Akomanin-Mensah, F., Wiredu, S., & Kovacs, Z. (2024). Combining NIR spectroscopy with chemometrics for discriminating naturally ripened banana and calcium carbide ripened banana. *npj Science of Food*, **8**, 86. <https://doi.org/10.1038/s41538-024-00327-1>
- Zhang, H., Huang, J., Li, T., Wu, X., Svanberg, S., & Svanberg, K. (2014). Studies of tropical fruit ripening using three different spectroscopic techniques. *Journal of Biomedical Optics*, **19**(6), 067001. <https://doi.org/10.1117/1.JBO.19.6.067001>