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Multi-spectral NIR-LED-Based Spectrometer Detects Calcium Carbide in Mango Fruit

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Abstract

In the Philippines, chunks of calcium carbide are usually used as a ripening agent for mango samples. However, the acetylene gas produced during the ripening process can cause harm to human health. Likewise, considering the country's economic standing, the development of low-cost and portable instruments is encouraged. To address these issues, a multi-spectral near-infrared light-emitting diode-based spectrometer was developed. This study aims to determine the calcium carbide residue detection capability using the developed spectrometer prototype. Partial least square regression and linear discriminant analysis showed 81% calcium carbide residue prediction capability and 88.9% correct classification, respectively. Therefore, the multispectral near-infrared light-emitting diode-based spectrometer prototype has the chance to detect calcium carbide chemical residue in mango fruit non-destructively.

Keywords:

Calcium carbide, mango fruit, non-destructive, detection, near-infrared spectrometer.

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Introduction

Calcium carbide is used as a source of acetylene gas, a ripening agent (Ropp, 2013), it is mostly used by mango vendors to ripen mangoes and sell to the market. However, acetylene gas may affect the neurological system of humans by inducing prolonged hypoxia. According to Per, et.al (2022), the findings are headache, dizziness, mood disturbances, sleepiness, mental confusion, memory loss, cerebral edema, and seizures for prolonged exposure.

In the Philippines, chunks of CaC2 were used to ripen mangoes. Retailers and wholesalers used 8 to 10 g CaC2 per kg of mango fruit (Lacap, 2019). In the presence of moisture, the CaC2 will release acetylene gas. Moreover, CaC2 powder contains traces of arsenic and phosphorus as per study conducted by Lakade et al. (2018), NIOSH, (2023).

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According to the World Health Organization, the allowable arsenic in drinking water is 10 ppb. This is likewise carcinogenic according to National Institute for Occupational Safety and Health if humans are exposed to more than 15 minutes of 2 μg arsenic per cubic meter of air (Mehra & Patel, 2024, Rossel, 2008). Moreover, according to the compendium of contaminants regulations authored by the Food Safety and Standards Authority of India, the allowable arsenic amount in any fruit pulp is 0.2 ppm (FSSAI, 2011, Lacap et al., 2019). In the study conducted by Nurasmat et al. (2021), a 5 g CaC2 sachet applied to 230 g of mango fruit was found to have 6.5 ppb arsenic residue. Considering the Philippines uses 8 to 10 g CaC2 per kg of mango fruit, it is probable that mangoes have more than or equal to 10 ppb arsenic residue. Therefore, it is possible that mangoes in the Philippines market can pose a threat to human health (Kapoor & Iyer, 2024).

Considering calcium carbide's harmful effects on human health, detecting calcium carbide chemical residue is important (Nurasmat et al., 2021). Through this method, consumers can prevent foodborne illnesses and ensure food safety, allowing them to make informed choices and avoid potentially harmful fruits (Sonwal, et. al, 2023; Lakade et al., 2018).

Also, by detection method, fruit quality can be monitored and ensures that they are not artificially ripened with harmful chemicals. It helps in the removal of unsafe products from the market, thus protecting public health (Vidhya, et.al, 2025; Sio, 2025).

Likewise, through calcium carbide detection method, the government can enforce regulations in violations of food safety laws if the presence of calcium carbide were confirmed during food production (Sreenivasu et al., 2022).

The detection of calcium carbide can help minimize environmental hazards by preventing the improper disposal or leaking of calcium carbide in water sources (Ponduri & Mohan, 2021). Likewise, preventing the accidental release of acetylene into the atmosphere which may affect air quality.

Efficient detection methods can help ensure that the correct amount of calcium carbide is used in manufacturing processes, thus reducing waste and ensuring the efficiency of operations. Moreover, early detection of calcium carbide presence or leaks allows for timely intervention, reducing the risk of damage or loss.

Various studies were conducted to detect pesticide residues in fruits and vegetables. Some of these studies involve using innovative technologies and methods (Per et al., 2007). One to mention is the near-infrared spectroscopy. Near-infrared spectroscopy (NIRS) is a rapid, precise, and non-destructive technique that has shown potential in the determination of numerous chemical and physical properties of foods and food products (Williams & Norris, 2001).

However, commercially available NIR spectrometers are bulky and expensive, costing 41,844 USD, therefore, a portable multispectral NIR-LED-based spectrometer prototype was developed. It was based on selecting and designing multispectral light-emitting diodes at the Near-infrared absorption region (Rodriguez-Macadaeg, et.al, 2024). This is likewise based on the suggestions from the study conducted by Okeke, et.al (2022) to improve and innovate calcium carbide detection technologies that can strengthen national and international agencies in reinforcing restrictions on the use of toxicants for fruit ripening, especially for exported products.

The evaluation of the portable multispectral NIR-LED-based spectrometer prototype is vital to know if it has the potential to detect calcium carbide residue in mango fruits (Williams, 2004). Likewise, the goal is for the Philippines to develop a low-cost instrument useful for the non-destructive determination of food's chemical and physical properties for food security and economic development.

Materials and Methods

Research Design

This experimental research involves chemometric data for analysis and evaluation of the prototype. Chemometric data includes both qualitative and quantitative data, thus, this research employs both qualitative and quantitative data analysis methods and techniques.

Multispectral NIR-LED-based spectrometer prototype

The prototype (Figure 1), costing 959 USD consists of the 12V DC Power supply, a laptop, and the black box with the microprocessor NIR-LED circuit board. All the data gathered through the graphical user interface were saved as a .txt file for partial least square regression and linear discriminant analysis. The circuit board is composed of Near Infrared Light Emitting Diodes (700, 980, 1050, 1200, 1300, 1450, 1550, 1600, and 1650 nm) with InGaAs detector, amplifier, transistors, and capacitors. The board was interfaced with an Arduino-DUE that serves as a microprocessor of digital and analog I/O signals.

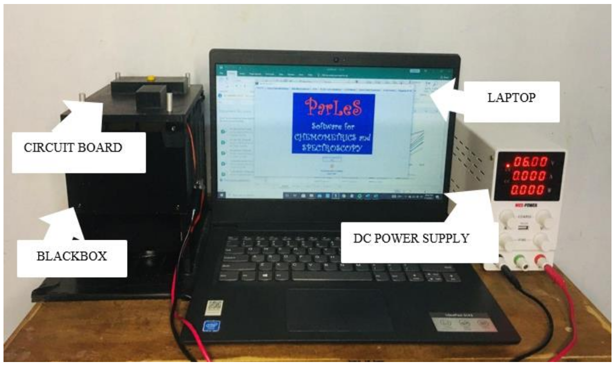

Figure 1. Multispectral NIR-LED-based spectrometer system prototype

Mango and Calcium Carbide Concentration

Pesticide-free mangoes were harvested from a house backyard located at Casiaman, Bacnotan, La Union during summer months 90 days after the flowering period. The floatation method was used to ensure that all the samples were at the same maturity stage. Different amounts of calcium carbide were wrapped in separate newspapers and placed inside a box with three (3) mango samples weighing approximately 1 kg for three (3) days and until ripened, duplicating the market vendor's practice. The seven (7) treatments were as follows:

- T0- 0, no calcium carbide.
- T1- 0.5 g calcium carbide
- T2- 1 g calcium carbide
- T3- 2 g calcium carbide
- T4- 3 g calcium carbide
- T5- 4 g calcium carbide
- T6- 10 g calcium carbide

The samples were scanned at three repacks with three replicates in each treatment using the prototype after 3 days of storage. The prototype scanned each mango fruit surface three times at three different points. All the 189 data gathered through the graphical user interface was saved using a txt file for analysis.

The sample treatments were validated using pure calcium carbide. The six (6) different amounts of calcium carbide (0.5, 1, 2, 3, 4, and 10 g) were placed in a sample holder and put inside the blackbox for NIR spectral scanning using the prototype. There were three replicates in each pure calcium carbide and scanned at three repacks. All the 162 data gathered through the graphical user interface was saved using a txt file for analysis.

Spectral Data Gathered

The multispectral NIR-LED-based spectrometer prototype was used to obtain spectra for each of the 21 mango fruit samples. Three replicates were carried out for each sample with three repacks per replicate. The mango fruit sample to be scanned was placed in the sample holder inside the blackbox below the circuit board. To address potential issues of cross-contamination, control treatment or mango fruit samples with no calcium carbide to increasing amount of calcium carbide in mango fruit samples was the sequenced of mango fruit sample scanning.

Data Analysis

Quantitative and qualitative spectral data analyses were performed using partial least squares (PLS) regression and discriminant analysis (DA) using Parles v.3.1 software (Viscarra Rossel) and NCSS 2024 v24.0.2 (NCSS, LLC, Kaysville, Utah, USA), respectively. For PLSR analysis, the 189 spectral data for mango samples with calcium carbide and 162 spectral data for pure calcium carbide were divided into a calibration ($n = 126, 108$) and independent validation ($n = 63, 54$) sample sets, respectively, based on the leave-one-variety-out sampling method. This method involved using the spectral data for different calcium carbide chemical residue concentrations from two of the three replicates as calibration samples, while the spectra from the remaining replicate were used as the independent validation samples. Aside from the analysis with the leave-one-variety sampling method, an analysis that made use of all the replicates with preprocessing treatments was also performed.

Several preprocessing techniques, including standard normal variate (SNV), multiplicative scattering correction (MSC), and mean centering, were used. The prediction model of the multispectral NIR-LED-based spectrometer prototype was derived from the developed best fit calibration and validation models. This study aims to determine the predictive capability of the prototype; thus, only the best fit prediction model was presented.

For the qualitative analysis, linear discriminant analysis was performed using the averaged raw spectral data for both experimental samples with all the replicates. The mango samples treated with seven levels (0, 0.5, 1, 2, 3, 4, and 10) of calcium carbide concentrations, and six (0, 0.5, 1, 2, 3, 4, and 10) levels of pure calcium carbide were classified according to the calcium carbide chemical residue concentration as detected by the multispectral-NIR-LED-based spectrometer prototype.

Results and Discussions

Pure Calcium Carbide

Qualitative analysis revealed 73.3 % correct classification of pure calcium carbide (Table 1) and quantitative analysis revealed R2 of 0.54 and 0.49 for the calibration model and validation model, respectively using SNV pre-processing technique (Table 2). Moreover, spectral absorbance revealed a possible calcium carbide spike at 1600 nm wavelength (Figure 2). Although the prototype could detect something, it was poor (Williams, 2005). Maybe this can be attributed to the high noise received at 0.5 g which is the first sample being scanned (Vickers, 1979). It was detected by the prototype at a high level which may connected to the InGaAs photodiode that actually can detect a high amount of chemical gas.

Table 1. Correction classification of pure calcium carbide different concentrations

	Predicted						
Actual	0.5	1	2	3	4	10	**Total**
0.5	2	0	0	0	0	1	3
1	0	3	0	0	0	0	3
2	0	0	2	1	0	0	3
3	0	0	0	2	0	1	3
4	0	0	0	0	3	0	3
10	1	0	0	0	0	2	3
Total	3	3	2	3	3	4	18

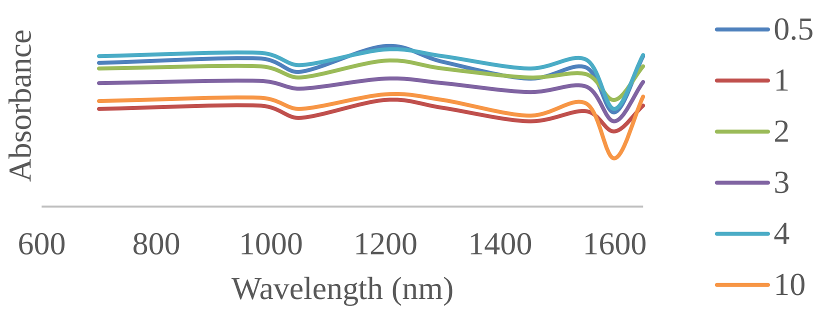

Figure 2. Pure calcium carbide raw spectra

Table 2. PLS model prediction statistics for the determination of pure calcium carbide

Samples	Pre-Processing	F	Calibration		Validation	
			R2	RPD	R2	RPD
ALL	MSC	2	0.028	0.74		
	SNV	2	0.543	0.82		
RPK1-RPK2	Raw	2	0.272	0.81	0	1.07
	MSC	4	0.234	0.87	0.026	0.77
	SNV	3	0.431	0.8	0.488	0.79
RPK2-RPK3	Raw	2	0.192	0.82	0.008	0.67
	MSC	2	0.003	0.81	0.392	0.76
	SNV	2	0.033	0.97	0.339	0.26
RPK1-RPK3	Raw	3	0.094	0.92	0.392	0.64
	MSC	2	0.003	0.94	0.209	0.89
	SNV	2	0.128	1.05	0.45	0.53

F=PLS factor number; R2 = coefficient of determination;

RPD=Relative Percent Difference

Moreover, the calibration and validation models (Table 2) developed were poor and not recommended for application (Williams, 2005). This may be attributed to the noise signals received by the photodiode since the prototype detected the same kind of chemical and maybe cannot determine the amount by concentrations (Vickers, 1979). Therefore, the prototype only detected the calcium carbide and not the concentrations, meaning all the concentrations may be perceived as only one kind.

Mango Fruit with Calcium Carbide

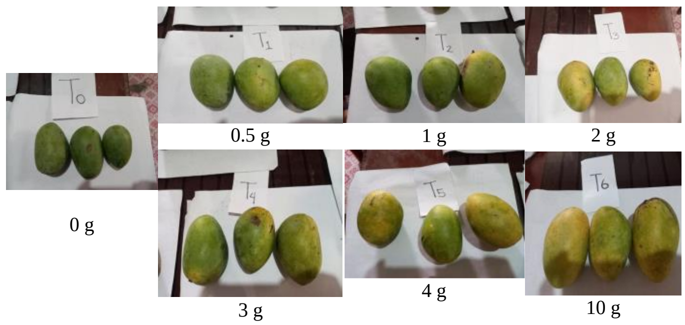

Figure 3. Mango fruit in different amounts of calcium carbide after 3 days

After three (3) days of storage, the majority of the mango fruits were ripened. The stored mango fruit (Figure 3) at different calcium carbide concentrations (0, 0.5, 1, 2, 3, 4, and 10 g) were scanned thereafter. Raw spectra of the different amounts of calcium carbide (Figure 4) showed slight differences among the samples nonetheless, the prototype detected something common among the samples at 1600 nm, 1550 nm, and 1000 nm. This may be attributed to the noise signals received by the photodiode since the prototype detected the same kind of chemical and maybe cannot determine the amount by concentrations (Vickers, 1979).

Figure 5 shows the PLS beta or regression coefficients of calcium carbide in mango fruit at an optimum number of factors. The wavelengths that are relevant to the identification of the presence of calcium carbide were identified. For instance, at 1300 nm peak pertains to methylene and 1600 nm pertains to alkenes which are related to the chemical composition of acetylene gas produced by calcium carbide (Workman, Jr., J, & L. Weyer, 2007, World Health Organization, 2022).

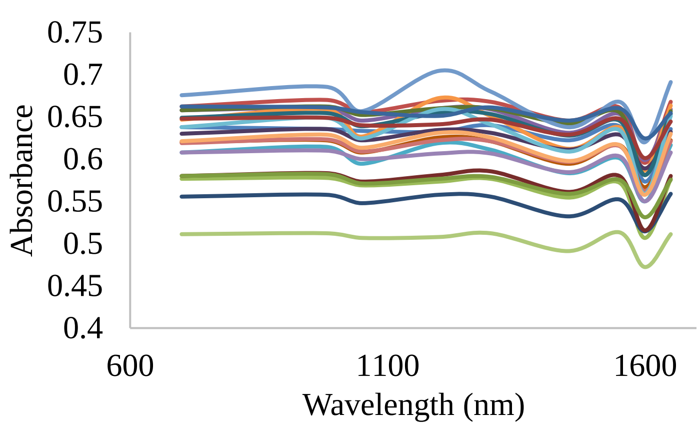

Figure 4. Calcium carbide residue in mango fruit raw spectra

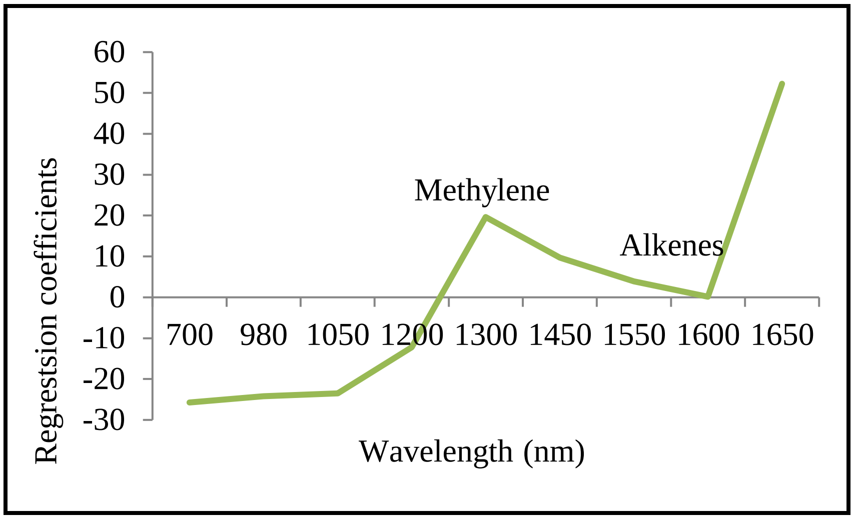

Figure 5. Regression coefficient for the different concentrations of calcium carbide

Table 3. Correction classification of calcium carbide chemical residue in mango fruit

	Predicted							
Actual	**0**	**0.5**	**1**	**2**	**3**	**4**	**10**	**Total**
0	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**3**
0.5	**0**	**3**	**0**	**0**	**0**	**0**	**0**	**3**
1	**0**	**0**	**2**	**0**	**1**	**0**	**0**	**3**
2	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**3**
3	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**3**
4	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**3**
10	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**3**
Total	**3**	**3**	**2**	**4**	**3**	**3**	**3**	**21**

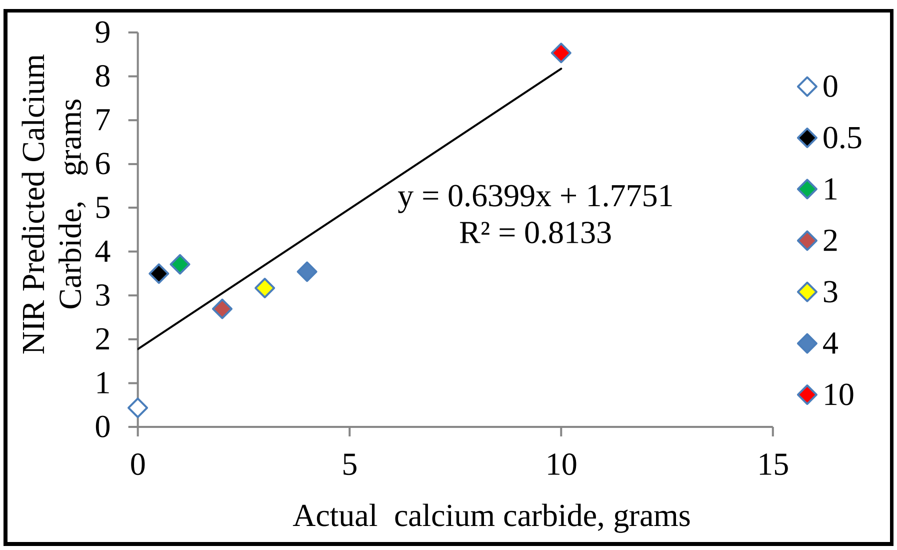

Figure 6. Prediction capability of the Multi-spectral NIR LED-based Spectrometer prototype

Discriminant analysis revealed 88.9% correct classification of calcium carbide in mango fruits (Table 3) while PLSR revealed 81.33% calcium carbide residue prediction capability of the prototype (Figure 6) (Williams, 2005). Therefore, the prototype has the chance to detect calcium carbide chemical residue in mangoes.

Conclusions

Qualitative analysis revealed 88.9% correct classifications of calcium carbide concentrations in mango fruit, and quantitative analysis showed a coefficient of determination (R2) of 0.81. Likewise, methylene and alkenes/ethylene were detected as related to the chemical composition of acetylene gas produced by calcium carbide. Therefore, the multispectral NIR-LED-based Spectrometer prototype has the chance to detect calcium carbide chemical residue in mango fruit. However, further study was needed to improve the design and functionality of the developed prototype, such as the use of another graphic unit interface, a voltage source, and an amplifier. Likewise, further study using other crops or fruits and pesticides to develop validation and calibration baseline models of the prototype.

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Conflict of Interest

The authors declared that no conflict of interest.

Author Contributions

All authors' contributions are equal for the preparation of research in the manuscript.

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