ENHANCED KNOWLEDGE IN SCIENCES AND TECHNOLOGY
e-ISSN: 2773-6385

EKST

Vol. 4 No. 1 (2024) 256-265
https://publisher.uthm.edu.my/periodicals/index.php/ekst

Comparison for Determination of Potassium Levels in Bananas by Fiber Optic Displacement Sensor and Atomic Absorption Spectroscopy

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DOI: https://doi.org/10.30880/ekst.2024.04.01.029

Article Info

Received: 28 December 2023
Accepted: 13 June 2024
Available online: 27 July 2024

Keywords

Fiber Optic Displacement Sensor 1, Atomic Absorption Spectroscopy 2, reflection 3, potassium 4, banana 5

Abstract

As humans body required an amount of 3.5 to 5 mEq/L of potassium to avoid Hypokalaemia, banana as one of nutritious fruit had been study of its potassium levels. Thus, a fibre optic displacement sensor (FODS) operation is based on intensity modulation technology, which employs a plastic optical fibre-based bundle as a probe and the surface of solution sample as the reflector is demonstrated to assess potassium in bananas. There are many methods developed to obtain more accurate measurements of potassium concentration that require an instrument with high linearity and sensitivity. Therefore, an optical intensity-modulated sensor composed of diode laser with an output wavelength of 650 nm was developed to determine the concentration of potassium in bananas. Hence, the research observed the comparison of the FODS system with one of the conventional methods which is Atomic Absorption Spectroscopy (AAS), because AAS is widely known for quantitative determination of chemicals substance or materials. AAS can detects elements in liquid or solid samples by using certain wavelength of electromagnetic radiation from a light source. The research yielded a gradient of 0.0000840469 V/mg/L for FODS and 0.0011100000 mg/L for AAS with sensitivity for both exceeding 99%. The approach method offers a practical solution for assessing potassium levels in bananas, real-time monitoring the level of substance in samples, and providing a convenient and high-sensitivity system.

1. Introduction

The potassium concentration contained in bananas is widely known in public because they are consumed from early childhood to adulthood to fulfil the need for potassium in the hope of preserving the balanced of fluids in the body to remain healthy [4,5,6]. There are various possible functional immunostimulatory of new fermented unripped banana powder as a food ingredient [12]. Nutritional contents that basically content in bananas are protein, carbohydrates, fibre and minerals such as potassium (K), magnesium (Mg), phosphorus (P), iron (Fe), sodium (Na) and calcium (Ca) [19]. By focusing on the detection of potassium levels that are contained in bananas, an application of an optical sensor will be featured.

An optical sensor is a device that detects and measures light or changes in light intensity. It can be based on various principles such as absorption, reflection, refraction, or emission of light. They can utilize different types of detectors, such as photodiodes or phototransistors, to convert light signals into electrical signals for further processing [15]. Hence, fibre optic displacement sensor (FODS) operation is based on intensity modulation technology, which employs a plastic optical fibre-based bundle as a probe and a flat mirror plane as the reflecting surface [21]. FODS can detect a variety of parameters, including light intensity, vibration, temperature, pressure, accelerometer calibration, strain, liquid level, pH, chemical analysis, concentration, density, refractive index of liquids, and so on [10]. FODS are also known for their high sensitivity in detecting minute changes in displacement or position [15].

To ensure the accuracy in determination of potassium levels from the method of FODS, the data from an Atomic Absorption Spectroscopy (AAS) will be used as a benchmark. AAS can measure different types of metal, one of them is potassium [7]. Atomic absorption spectrometry (AAS) can detect elements in liquid or solid samples by using certain wavelengths of electromagnetic radiation from a light source. Individual elements absorb wavelengths differently, and the absorbances of these elements are evaluated against standards. AAS, in fact, takes advantage of the various radiation wavelengths absorbed by different atoms [1].

In summary, this paper introduces an advanced method employing FODS for the accurate determination of potassium levels in bananas. The unique capabilities of FODS, including high sensitivity and real-time monitoring, make it a promising tool for ensuring the nutritional quality of this widely consumed fruit.

2. Mechanism of FODS and AAS

Fig. 1 shows the visualization of the working principle of the FODS in detecting the potassium in banana extract solution. Reflective intensity modulation technique has been carried out through an optical fibre (transmitter) and other optical fibre that serves as receiver of reflected signal from the surface of the solution (sample). As the resemble like a concave mirror, the assumption is made for the curvature of the solution's surface. It is having a virtual focal point and a center located at two times of virtual focal point [11]. The refractive index affects the reflection of light through the Fresnel equations, which describe the relationship between reflection and the refractive index of a material. The magnitude of the refractive index can influence the intensity of reflection, with higher refractive indices leading to stronger reflections. Thus, when the refractive index of the first medium (n1) is higher than the refractive index of the second medium (n2), reflection occurs.

The light from original point, *O* and at a distance of *TR* is travel directly on the meniscus, the light concentrated at point *O'* after reflected by the meniscus and becomes another emitting point source virtually and collected by the RF. The sensor probe tip should be positioned as close as possible to the solution surface to optimize the amount of received light. The curve reflection phenomenon also needs to be noted as is used to clarify the working principle of FODS.

For analysis, the shifting of the sensor probe away from surface (fixed reference) passing through its virtual point will produce two peaks of voltage. The two peaks of voltages define the maximum intensity occur due to the reflected light from the meniscus corresponding to the minimum surface energy on the surface. As the probe moves away from the meniscus, the intensity collected is a result of increasing the size of the acceptance angle. The larger the acceptance angle, the bigger the cone of the light, thus more lights can be captured by the RF.

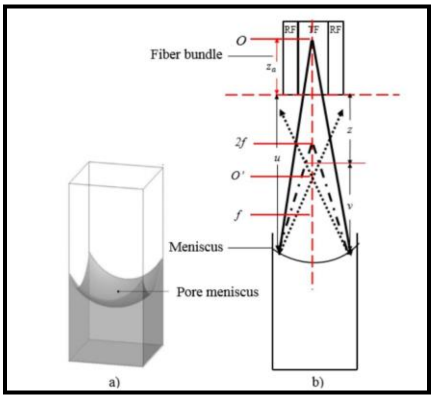

Fig. 1 *(a) The design of pore meniscus in a cuboid cuvette; (b) The visual of geometry of intensity modulation mechanism using a bundle fibre probe on a liquid surface [11]*

Besides, there is a different concept of FODS and AAS which FODS measure the intensity of received light that reflected back from the surface of solution, while AAS measure the absorption energy of light by the atoms to determine the concentration of specific elements in the sample. When a sample is atomized and exposed to light at a unique wavelength, the energy is absorbed by the atoms, causing the electrons to move from the ground state to excited states.

AAS as shown in Fig. 2 is an analytical technique used to determine the concentration of metal atoms or ions in a sample. The working principle of AAS is based on the absorption of light by free atoms in a sample [8]. When the sample is atomized, typically in a flame or a graphite furnace, the free atoms are exposed to light, typically produced by a hollow-cathode lamp. The light causes the electrons within the atoms to absorb energy and move from their ground state to excited states. The amount of energy absorbed is directly related to the transition that occurs, and since the electronic structure of every element is unique, the radiation absorbed represents a unique property of each individual element [17]. The AAS instrument consists of four main components: the light source, the atomization system, the monochromator, and the detection system. The light source produces light of a specific wavelength that is characteristic of the element being analysed. The atomization system atomizes the sample, either in a flame or a graphite furnace, to create free atoms. The monochromator separates the light into its component wavelengths, and the detection system measures the intensity of the light at the specific wavelength of the element being analysed.

Fig. 2 *The Atomic Absorption Spectroscopy (AAS) system*

3. Material and Method

There are 5 types of bananas that commonly founded in Malaysian market, which is Pisang 40 Hari, Pisang Tanduk, Pisang Nipah, Pisang Berangan, and Pisang Carvendish. Fig. 3 shows the sample of extract banana solutions. 20g of each type of bananas is peeled and diced. Next, mash dried bananas using a blender until obtain a smooth and uniform paste without remain any chunks or fibres. Then, put it in the furnace for 12 hours at about 526°C. Weight again the banana pastes using a digital scale to determine the amount used for extraction. Later, deionized water is selected as an appropriate solvent to extract the potassium. Mix the weighed amount of banana paste to the solvent which is 10% of nitric acid, HNO_3 in a container. Stir and shake the mixture vigorously to ensure thorough mixing and extraction of the potassium from the banana paste. Then, let the mixture stand for 30 minutes, to allow the potassium ions to diffuse into the solvent. After the standing period, filter the mixture using filter paper to remove any solid particles or impurities. This results in a clear banana extract solution. Later, pour the filtered banana extract solution into a clean and labelled container, ensuring that the volume is accurately measured. The container should be suitable for storage and subsequent analysis. As it is complete, store the banana extract solution in a cool, dark place or refrigerate it to prevent degradation and maintain its stability until further analysis.

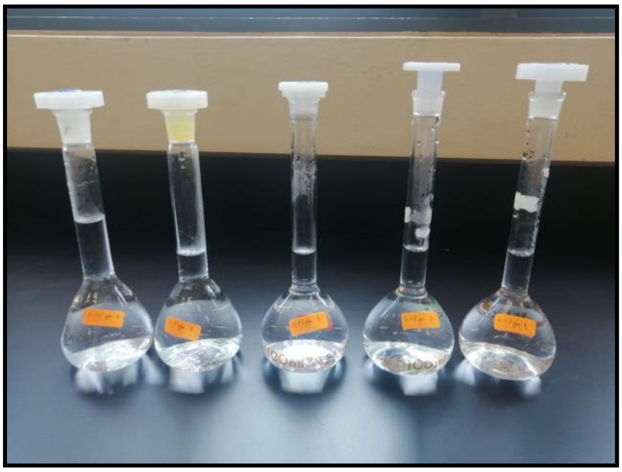

Fig. 3 *The sample of banana extract solution of Pisang 40 hari, Pisang Tanduk, Pisang Nipah, Pisang Berangan and Pisang Carvendish*

Fig. 4 shows a schematic diagram of a fibre optic displacement sensor that includes a He-Ne laser, a linear actuator, a bifurcated fibre bundle, an oscilloscope, and a laptop that is incorporated in the setup. As the light source, He-Ne lasers are needed, which is a continuous wave output with an output wavelength of 632.8 nm and a power output of 10 mW, are used. The bifurcated fibre bundle sensor probe, which consists of transmission fibre (TF) and receiving fibre (RF), is used in this method. The Autonics Corporation manufactured the 2m in length bifurcated fibre bundle probe. Thus, the tools used in the part of the AAS method are an analytical balance, measuring flask, test tube, tube shaker, porcelain cup, stirring rod, dropper, oven, Atomic Absorption Spectrophotometer (AAS), and muffle furnace. Materials used for the AAS method are, aquabidest, HNO_3, $HClO_4$.

The samples that be used are the standard potassium solution with 64 mg/L, 128 mg/L, 192 mg/L, 256 mg/L, and banana extract solution from *Pisang 40 Hari*, *Pisang Tanduk*, *Pisang Nipah*, *Pisang Berangan*, and *Pisang Carvendish*.

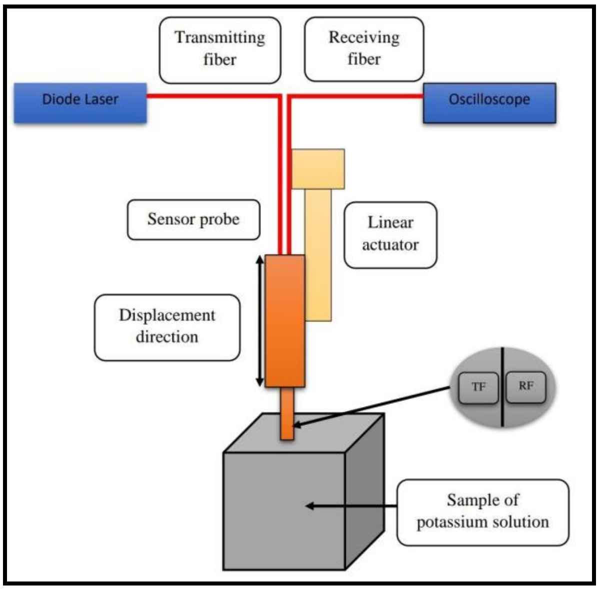

Fig. 4 *The design of fibre optic displacement sensor to determine the potassium levels in samples*

4. Results and Discussion

Fig. 5 shows a graph of output voltage versus displacement at different concentration of standard potassium solution from 64 mg/L to 256 mg/L. Based on the graph, the output voltage measurements decrease as the concentration of potassium increases.

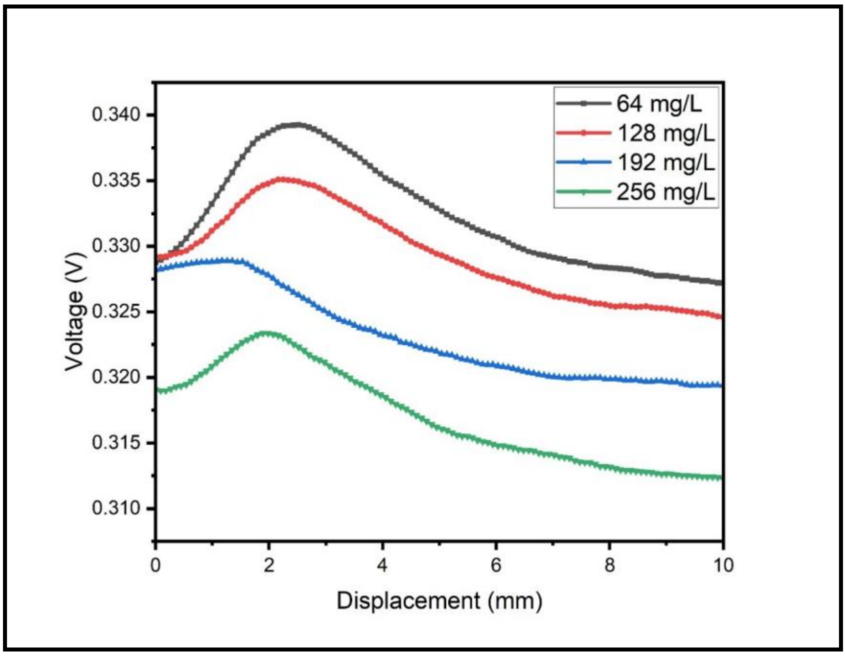

Fig. 5 *The graph of voltage versus displacement for standard potassium solution using FODS method*

The detector, which is a photodiode starts detecting the output voltage when the fibre bundle is place closely to the surface of the sample solution, 0mm from the sample solution. The fibre bundle then shifted to 10mm. At each position, the output voltage is measured by the photodiode so that data is obtained, which then the maximum output voltage for each variation concentration of potassium be observed. The maximum output voltage from a variation of potassium concentration is shown in Table 1.

Table 1 *The maximum output voltage of various concentrations of standard potassium solutions*

Concentration of Potassium (mg/L)	Maximum voltage (V)
64	0.3392
128	0.33507
192	0.3288
256	0.32336

Based on the data on the maximum output voltage of each concentration of standard potassium solutions, it will be analysed to obtain a linear equation. The linear equation from the standard potassium solutions becomes the reference with consideration the sensitivity value is higher and accurate with the equation y = -0.0000840469x + 0.34506 as shown in Fig. 6 with its gradient of 0.0000840469V/mg/L and its sensitivity based on its linearity greater than 99%.

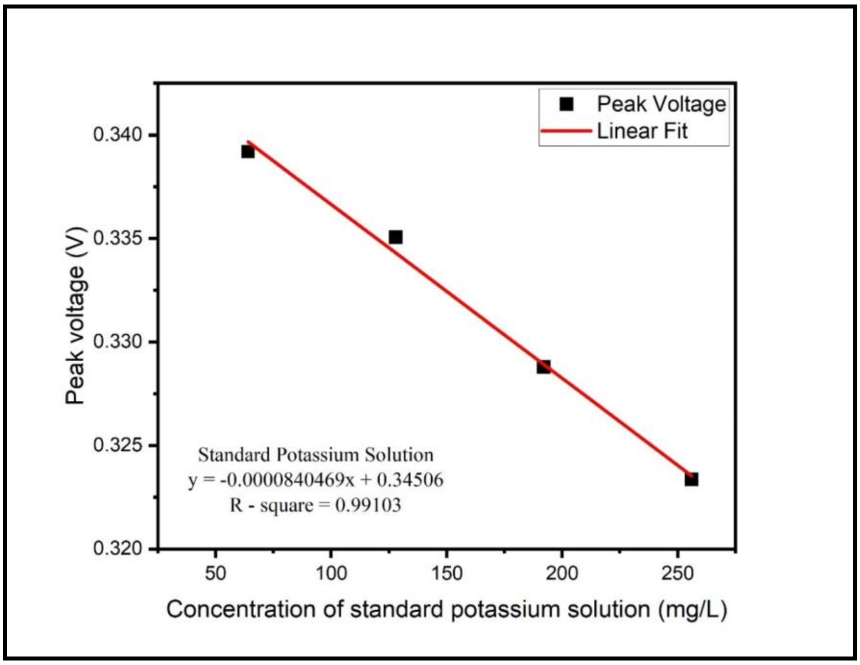

Fig. *6 Calibration curve of standard solution of potassium using FODS method*

Fig. 7 presents the maximum voltage peaks observed at a displacement point of approximately 3.0 mm, whereby *pisang carvendish* exhibits the highest value, followed by *pisang nipah*, *pisang 40 hari*. *pisang berangan*, and *pisang tanduk*. At this displacement level, the voltage peak reading for each banana is 0.30075V, 0.28365V, 0.30782V, 0.29342V, and 0.30967V, respectively as shown in Table 2. On the other hand, after passing the 3.0 mm point where the maximum voltages are obtained, the voltage reading starts to drop in an inverse square law manner until the maximum displacement of 10 mm. The declining pattern of the voltage is attributed to decreasing light intensity as the reflected light starts to diverge at a longer distance from the reflecting surface. It consequently limits the amount of light entering the RF since the width of the light acceptance cone of the fibre will increase as the displacement increases [11].

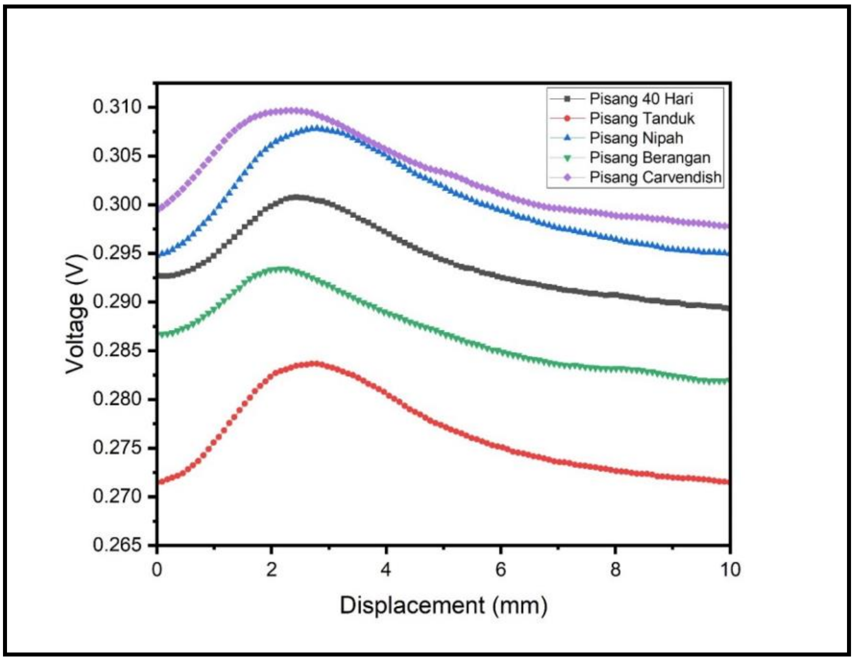

Fig. 7 *The graph of voltage versus displacement of FODS method for each banana extract solution.*

Table 2 *The maximum value of output voltage and concentration of potassium of five types of bananas using FODS method*

Type of bananas	Maximum voltage (V)	Concentration of Potassium (mg/L)
Pisang 40 hari	0.30075	527.2056
Pisang Tanduk	0.28365	720.6635
Pisang Nipah	0.30782	443.0859
Pisang Berangan	0.29342	614.4188
Pisang Carvendish	0.30967	421.0744

The data from the FODS methods were compared to the data from the AAS method. In contrast to the FODS system, which measures the intensity of light in form of an output voltage, AAS method determines the concentration of sample solution as the intensity of coloured solutions using spectrophotometer by allowing the substance to bind with colour-forming chromogens [8, 25]. The coloured solution absorbed the amount of electromagnetic radiation in the visible region of the spectrum is often directly proportional to the concentration of coloured species as defined by Beer-Lambert Law as represented in Fig. 85. The reference linear equation attained from the graph of the relation between the maximum value of absorption and the concentration of standard solution of potassium that same used in the FODS method, which y = 0.00111x + 0.00580 with gradient 0.00111mg/L and the sensitivity due to its linearity is more than 99%.

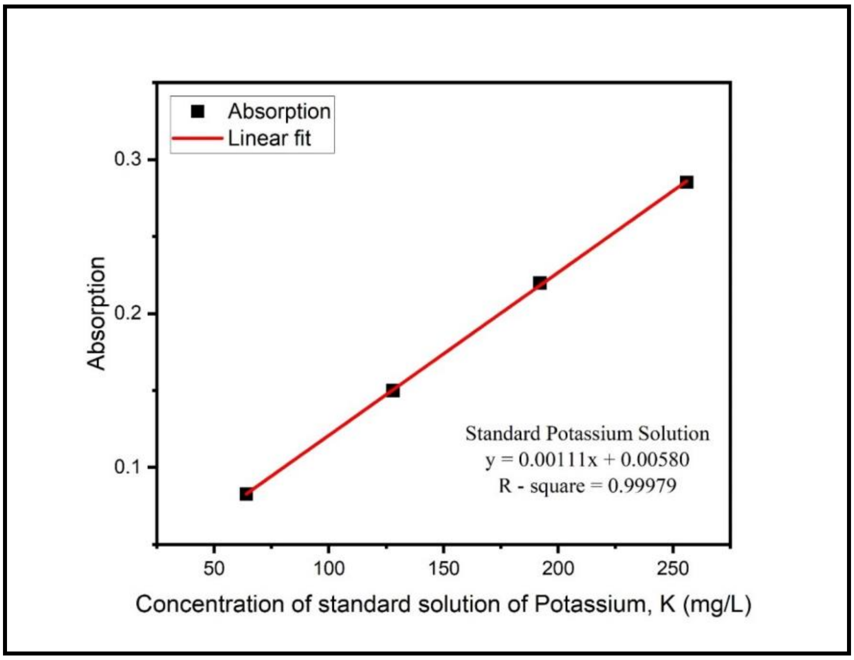

Fig. 8 *Calibration curve of standard solution of potassium using AAS method*

The absorption or the transmission of certain substances obtained by the observed colour. In addition, visible spectrophotometer use a prism to narrow down a certain range of wavelength, thus, the particular beam of light is passed through the solution samples.

Table 3 listed the maximum absorption value measured for each of the five types of banana extract solutions and the concentration of potassium content in five types of bananas that had been run in the FODS system.

Table 3 *The maximum absorption value and concentration of potassium of each various type of banana using AAS method*

Type of bananas	Maximum absorption	Concentration of Potassium (mg/L)
Pisang 40 hari	0.0695	573.8739
Pisang Tanduk	0.0849	712.6126
Pisang Nipah	0.0503	400.9009
Pisang Berangan	0.0727	602.7027
Pisang Carvendish	0.0579	469.3694

As comparison between both methods approached, the Table 4 shows the percentage difference of each type of bananas that range the highest different to 10.5226% only. Thus, the performance of FODS proven to be slightly close as the conventional method.

Table 4 *The maximum absorption value and concentration of potassium of each various type of banana using AAS method*

Type of bananas	Concentration of Potassium (mg/L)		Percentage difference (%)
	AAS	FODS	
Pisang 40 hari	573.8739	527.2056	8.1322
Pisang Tanduk	712.6126	720.6635	1.1298
Pisang Nipah	400.9009	443.0859	10.5226
Pisang Berangan	602.7027	614.4188	1.9439
Pisang Carvendish	469.3694	421.0744	10.2893

5. Conclusion

A fibre optic displacement sensor (FODS) based on the intensity modulation technology, with reflective intensity modulation technique was successfully employed as a potential system for detecting potassium concentration in various type of banana extract solution. One peak voltage was observed from the displacement curves during the evaluation of the various concentrations of potassium from 64 mg/L to 256 mg/L. Even though FODS focused on an output light beam which detects in form of an output voltage, while AAS focused on the absorption value of the sample solution, it shows that the sensitivity of both methods based on the linearity are greater than 99%. These results emphasize the proposed technique, characterized by its real-time capabilities, affordability, and simplicity making it as future method for potassium detection in bananas.

Acknowledgement

This research was supported by University Tun Hussein Onn Malaysia (UTHM) through Tier 1 (Vot Q407). Special thanks from the author for the Faculty of Applied Sciences and Technology (FAST) of University Tun Hussein Onn Malaysia, and Faculty of Science and Technology, University Sains Islam Malaysia for giving full support in instruments.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design, data collection, methodology, analysis and interpretation of results:*** *Muhammad Affendi Muhizan, Nurul Nadia Adnan and Nur Athirah Mohd Taib. All authors reviewed the results and approved the final version of the manuscript.*

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