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

EKST

Vol. 5 No. 2 (2025) 353-361
https://publisher.uthm.edu.my/periodicals/index.php/ekst

Determination of Trace Elements Concentration in Saba Banana Samples at Different Maturation Stages via ICP-MS

Nur Anisah Sahadi[1], Hatijah Basri[1*]

[1] *Department of Technology and Natural Resources, Faculty of Applied Sciences and Technology, UTHM Kampus Cawangan Pagoh, Hab Pendidikan Tinggi Pagoh, KM 1, Jalan Panchor, 84600, Pagoh, Muar, Johor, MALAYSIA.*

*Corresponding Author: hatijah@uthm.edu.my
DOI: https://doi.org/10.30880/ekst.2025.05.02.042

Article Info

Received: 30 December 2024
Accepted: 20 January 2025
Available online: 19 December 2025

Keywords

Trace Elements, ICP-MS, Nutritional Value, Soil, Saba Banana, *Pisang Nipah*

Abstract

Saba @ *Pisang Nipah* (Musa 'saba'), a hybrid banana variety, is valued for its export potential and nutritional properties. This study aimed to determine the concentrations of trace elements and evaluate their nutritional implications in Saba bananas at different ripening stages using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The analysis focused on detrimental elements such as arsenic (As), cadmium (Cd), chromium (Cr), and lead (Pb), which are known to pose health risks if consumed in excess. The findings revealed significant variations in these elements during ripening. Arsenic levels declined by 71.05%, from unripe (0.0038 mg/kg) to overripe (0.0011 mg/kg). Lead showed a 41.04% decline from unripe (0.0212 mg/kg) to overripe (0.0299 mg/kg), though it peaked in ripe bananas (0.0629 mg/kg). In contrast, chromium increased sharply, rising by 829.64% from unripe (0.0938 mg/kg) to overripe (0.8720 mg/kg). Cadmium levels rose by 80.00% from unripe (0.002 mg/kg) to ripe (0.0036 mg/kg) but decreased to 0.0026 mg/kg in overripe bananas. Despite these fluctuations, all trace element concentrations remained below the maximum permissible levels set by WHO/FAO Codex and EFSA, ensuring their safety for consumption. Nutritional analysis highlighted the benefits of ripe bananas, which contained the highest protein content (4.770 g/100g) and provided substantial energy (188 kcal/100g). Ripe bananas also had the highest carbohydrate content (47.0 g/100g), making them an energy-rich fruit. Dietary fiber, ash, and moisture contents remained consistent across all ripening stages (<0.001 g/100g), while fat content was negligible. In conclusion, this study demonstrates that Saba bananas are safe for consumption at all ripening stages, with beneficial nutritional properties, especially when ripe. Monitoring trace elements during ripening is essential to ensure food safety and optimize dietary benefits. Future research should explore mechanisms influencing trace element dynamics and establish strategies to enhance the nutritional value and safety of bananas.

1. Introduction

Bananas, particularly the Saba cultivar (*Pisang Nipah*), are a staple food in many parts of the world due to their rich nutritional composition and essential mineral content [1]. Known for their versatility and accessibility, bananas are a key source of carbohydrates, vitamins, and trace elements, which play critical roles in physiological processes such as enzymatic activity, cellular signalling, and immune regulation. Previous studies

have highlighted the importance of trace elements like zinc (Zn), iron (Fe), and manganese (Mn) in fruits, including bananas, for promoting human health [1,2]. Zinc is crucial for immune function and wound healing [3], while iron is essential for oxygen transport in the blood [4]. Manganese plays a role in bone formation and antioxidant defense, helping to protect cells from oxidative stress [5]. However, some trace elements, such as lead (Pb) and cadmium (Cd), can pose serious health risks when present in elevated concentrations due to their toxic effects [6]. Chronic exposure to these harmful metals can lead to neurological damage, kidney dysfunction, and increased risk of cancer [7]. Despite the global significance of bananas, limited research exists on how the concentrations of trace elements vary in bananas, especially across different stages of ripening.

The biochemical composition of bananas undergoes substantial changes during ripening, including variations in moisture content, sugar levels, and organic acids. Studies have focused extensively on these changes to understand their impact on flavour and texture [8]. However, there is a critical gap in knowledge regarding the shifts in trace element concentrations during the ripening process, particularly in the Saba cultivar. Understanding these variations is essential not only for assessing the nutritional quality of bananas but also for evaluating potential health risks associated with the accumulation of detrimental elements like arsenic (As), cadmium (Cd), and chromium (Cr) [9].

This study aims to address this knowledge gap by analysing the concentrations of both essential and potentially harmful trace elements in Saba bananas at different stages of ripening, using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). This advanced analytical technique offers high sensitivity, precision, and the ability to simultaneously detect multiple trace elements in complex food matrices [10]. Samples will be collected at various stages of development, ranging from green (unripe) to fully ripe, to capture the dynamic physiological changes during maturation. By focusing on both essential nutrients like zinc (Zn) and potentially harmful elements like lead (Pb) and cadmium (Cd), this study seeks to provide valuable insights into the nutritional quality and safety of Saba bananas, while also highlighting the potential implications of agronomic practices and environmental factors on trace element accumulation.

2. Materials and Methods

2.1 Materials

For this research, samples of Saba bananas (Musa 'saba'), also known locally as *Pisang Nipah*, were categorized into three distinct maturity groups: under-mature, mature, and over-mature. These classifications were determined based on their visual and textural characteristics, such as peel colour and firmness, which have been used in previous studies to differentiate maturity stages in bananas [11,12]. To ensure consistency and minimize variability, all banana samples were sourced from a single farm in Tampok, Johor. Importantly, all samples were harvested from the same tree to control for genetic and environmental factors that could influence ripening and trace element composition. This standardized sampling approach was critical for enhancing the reliability of the results, as differences in cultivation practices, soil composition, and microclimatic conditions can significantly impact trace element concentrations [1]. In addition to the banana samples, soil from the plantation was also collected to evaluate the potential influence of trace elements in the soil on the ripening stages of the bananas. Previous studies have highlighted the role of soil composition in contributing to the accumulation of both beneficial and detrimental elements in fruits. For instance, heavy metals like cadmium (Cd) and lead (Pb) in agricultural soils can translocate into fruits, influencing their safety for consumption [5]. The soil samples were analysed to establish a baseline for trace element levels and to assess their correlation with the concentrations found in the bananas during different maturity stages.

2.2 Methods

Banana and soil samples were prepared through acid digestion and analysed for trace elements using Inductively Coupled Plasma Mass Spectrometry (Agilent Technologies, 7800 ICP MS, Canada). Nutritional composition was evaluated using standard methods: carbohydrates were determined by difference, protein content by the Kjeldahl method, fat by Soxhlet extraction, ash by incineration, moisture by oven drying, dietary fiber by gravimetric analysis, and energy content was calculated based on macronutrient composition. Calibration and quality control procedures ensured the accuracy of results for both trace element and nutritional analyses.

2.2.1 Sample Preparation of Trace Elements Concentration

To determine trace element concentrations in Saba bananas at three maturity stages, 0.5–1.0 g of banana samples was weighed and digested with 10 mL of ultrapure nitric acid (HNO_3) (Spectrum Chemical Mfg, South San Pedro). For soil samples, 2 mL of hydrogen peroxide (H_2O_2) (Progressive Scientific, Malaysia) was added. The mixture was heated to 200°C to break down the organic matrix and release trace elements, then cooled to 60°C. The digested samples were diluted with ultrapure water to 1000 mL, ensuring detectable trace element

Enhanced Knowledge in Sciences and Technology Vol. 5 No.2 (2025) p. 353-361

levels for ICP-MS (Agilent Technologies, 7800 ICP MS, Canada) analysis. A 10 µL aliquot of the diluted solution was prepared for injection. Calibration was achieved using standard solutions prepared from certified stock solutions. Results from the ICP-MS analysis were used to quantify trace elements across the maturity stages [13,14].

2.2.2 Determination of Carbohydrate Content

To determine the carbohydrate content in Saba banana samples at different maturation stages, the samples were first homogenized using a blender (Prime Scientific, Germany). A precisely measured 2 g of the homogenized sample had been taken for analysis. The carbohydrates had been hydrolysed by adding 50 mL of 2N hydrochloric acid (HCl) (Bendosen, Malaysia) and heating the mixture in a boiling water bath for 30 minutes. After cooling the mixture to room temperature, it was neutralized using sodium hydroxide (NaOH) (Bendosen, Malaysia) until the pH had reached 7. The mixture was then been filtered to remove solid particles. The carbohydrate content was analysed using the phenol-sulphuric acid method, where the absorbance measured at 490 nm using a spectrophotometer (BIOBASE, BK-UV1000, China). The carbohydrate content had been calculated using a standard glucose curve [15,16].

2.2.3 Determination of Protein Content

The protein content in Saba banana samples at different maturation stages was determined using the Kjeldahl method. The procedure began with weighing 1 g of the homogenized sample, which had been placed in a Kjeldahl digestion flask (Fisher Scientific, Pennsylvania). To the flask, 15 mL of concentrated sulfuric acid (H_2SO_4) (MERCK, Germany) and a catalyst (copper sulphate and potassium sulphate) were added. The mixture was heated until it had become clear, indicating complete digestion. The digested sample was then distilled with 40% sodium hydroxide (NaOH) (MERCK, Germany) and the released ammonia was collected in a boric acid solution (Borax 20 Mule, USA). The collected ammonia had been titrated with 0.1N hydrochloric acid (HCl) (Bendosen, Malaysia) using an appropriate indicator, such as methyl red. The nitrogen content had been calculated and multiplied by a conversion factor (typically 6.25) to determine the protein content [17,18]. The calculation for protein content of samples was calculated by using Eq. (1) for nitrogen content and followed by Eq. (2) for protein content.

$$Nitrogen(g/100g) = \frac{(Volume\ of\ HCl\ used\ (L) \times Normality\ of\ HCl(N) \times 14)}{Weight\ of\ Sample\ (g)} \times 100 \quad (1)$$

$$Protein\ Content(g/100g) = Nitrogen(\frac{g}{100g} \times Protein\ Coversion\ Factor\ (6.25) \quad (2)$$

2.2.4 Determination of Fat Content

To determine the fat content in Saba banana samples at different maturation stages, 5 g of the homogenized sample was weighed and placed in an extraction thimble (Fisher Scientific, Pennsylvania). The fat was extracted using a Soxhlet extractor with petroleum ether (MERCK, Germany) as the solvent for 6-8 hours. After extraction, the solvent had been evaporated using a rotary evaporator (IKA, RV 10). The extracted fat residue was then been dried in an oven drying (Carlssoon Technologies, MEMMERT, UNB-200, Malaysia) at 105°C for 1 hour. The dried fat residue was weighed, and the fat content was calculated as a percentage of the initial sample weight [19,20]. The fat content of the samples was calculated by using Eq. (3).

$$Fat\ Content(g/100g) = \frac{Weight\ of\ Extracted\ Fat\ (g)}{Weight\ of\ Initial\ Sample\ (g)} \times 100 \quad (3)$$

2.2.5 Determination of Ash Content

The ash content in Saba banana samples at different maturation stages was determined by first weighing 2 g of the homogenized sample and placing it in a pre-weighed crucible (Kumpulan Scientific, Malaysia). The sample was then incinerated in a muffle furnace (Carbolite Elf11/14b/301 Bench Top Muffle Furnace) at 550°C until a white or light grey ash had been obtained, which usually had taken 4-6 hours. After incineration, the crucible had been cooled in a desiccator (Kumpulan Scientific, Malaysia). The crucible with the ash residue had been weighed to determine the ash content [19,20]. The ash content of the samples was calculated by using Eq. (4).

$$Ash\ Content(g/100g) = \frac{Weight\ of\ Ash\ Residue\ (g)}{Weight\ of\ Initial\ Sample\ (g)} \times 100 \quad (4)$$

2.2.6 Determination of Moisture Content

The moisture content in Saba banana samples at different maturation stages was determined by weighing 5 g of the homogenized sample and drying it in an oven drying (Carlssoon Technologies, MEMMERT, UNB-200, Malaysia) at 105°C until a constant weight was achieved. The difference in weight before and after drying was used to calculate the moisture content as a percentage of the initial sample weight [19,20]. The moisture content of the samples was calculated by using Eq. (5).

$$Moisture\ Content(g/100g) = \frac{Weight\ Before\ Drying\ (g) - Weight\ After\ Drying(g)}{Weight\ Before\ Drying(g)} \times 100 \quad (5)$$

2.2.7 Determination of Dietary Fiber

The dietary fiber content in Saba banana samples at different maturation stages was determined by using the enzymatic-gravimetric method. The sample had been treated with a series of enzymes, including α-amylase (TMS, Megazyme Malaysia, Malaysia), protease (TMS, Megazyme Malaysia, Malaysia), and amyloglucosidase (TMS, Megazyme Malaysia, Malaysia), to remove starch and protein. The remaining residue had been filtered, washed with ethanol (Kumpulan Scientific, Malaysia) and acetone (1 MalaysiaBioLab, Malaysia), dried, and weighed to determine the dietary fiber content [18,19]. The total dietary fiber of the samples was calculated by using Eq. (6).

$$Dietary\ Fiber(g/100g) = \frac{Weight\ of\ Residue\ (g)}{Weight\ of\ Initial\ Sample\ (g)} \times 100 \quad (6)$$

2.2.8 Determination of Energy Value

The energy value of Saba banana samples at different maturation stages was calculated based on the proximate analysis results. The energy value is determined using the Atwater factors, where the carbohydrate, protein, and fat contents are multiplied by their respective caloric values (4 kcal/g for carbohydrates and proteins, 9 kcal/g for fats) and summed to obtain the total energy value in kcal per 100 g of the sample [20]. Eq. (7) was used to calculated the total energy value of each sample.

$$Energy\ Value\ (kcal/100g) = \left[Carbohydrate\ Content\left(\frac{g}{100g}\right) \times \frac{4kcal}{g}\right] + \left[Protein\ Content\left(\frac{g}{100g}\right) \times \frac{4kacl}{g}\right] + \left[Fat\ Content\ \left(\frac{g}{100g}\right) \times \frac{9kcal}{g}\right] \quad (7)$$

3. Results and Discussion

The results revealed significant variations in trace element concentrations and nutritional composition across the different maturity stages of Saba bananas. Trace elements were found to decrease as the fruit ripened, remaining within safe consumption limits, while nutritional content, including carbohydrates, protein, and energy, varied with maturity. These findings provide insights into the safety and nutritional benefits of Saba bananas throughout their ripening process.

3.1 Determination of Trace Elements Concentration

Fig. 1(a) shows that the soil sample exhibited significant arsenic levels (0.4538 ± 0.0185 µg/mL), while banana samples showed a progressive decline in arsenic concentrations from unripe (0.0038 ± 0.0002 µg/mL) to ripe (0.0014 ± 0.0000 µg/mL) and overripe stages (0.0011 ± 0.0000 µg/mL). This decline reflects the plant's capacity to limit arsenic translocation to the fruit via root-based exclusion mechanisms and sequestration [21]. Studies indicate that arsenic bioavailability is influenced by soil properties, including pH and organic matter, which affect arsenic mobility [22]. The levels of arsenic found in Saba bananas are consistent with findings by Islam et al (2023) [23], who reported similar low concentrations of arsenic in banana tissues, with mean concentration of as were found to be 2.52 µg/mL indicating effective detoxification mechanisms in the plant. Despite its presence, arsenic levels in all samples were below the FAO/WHO limit of 100 µg/mL, ensuring the fruit's safety at all ripening stages.

Enhanced Knowledge in Sciences and Technology Vol. 5 No.2 (2025) p. 353-361

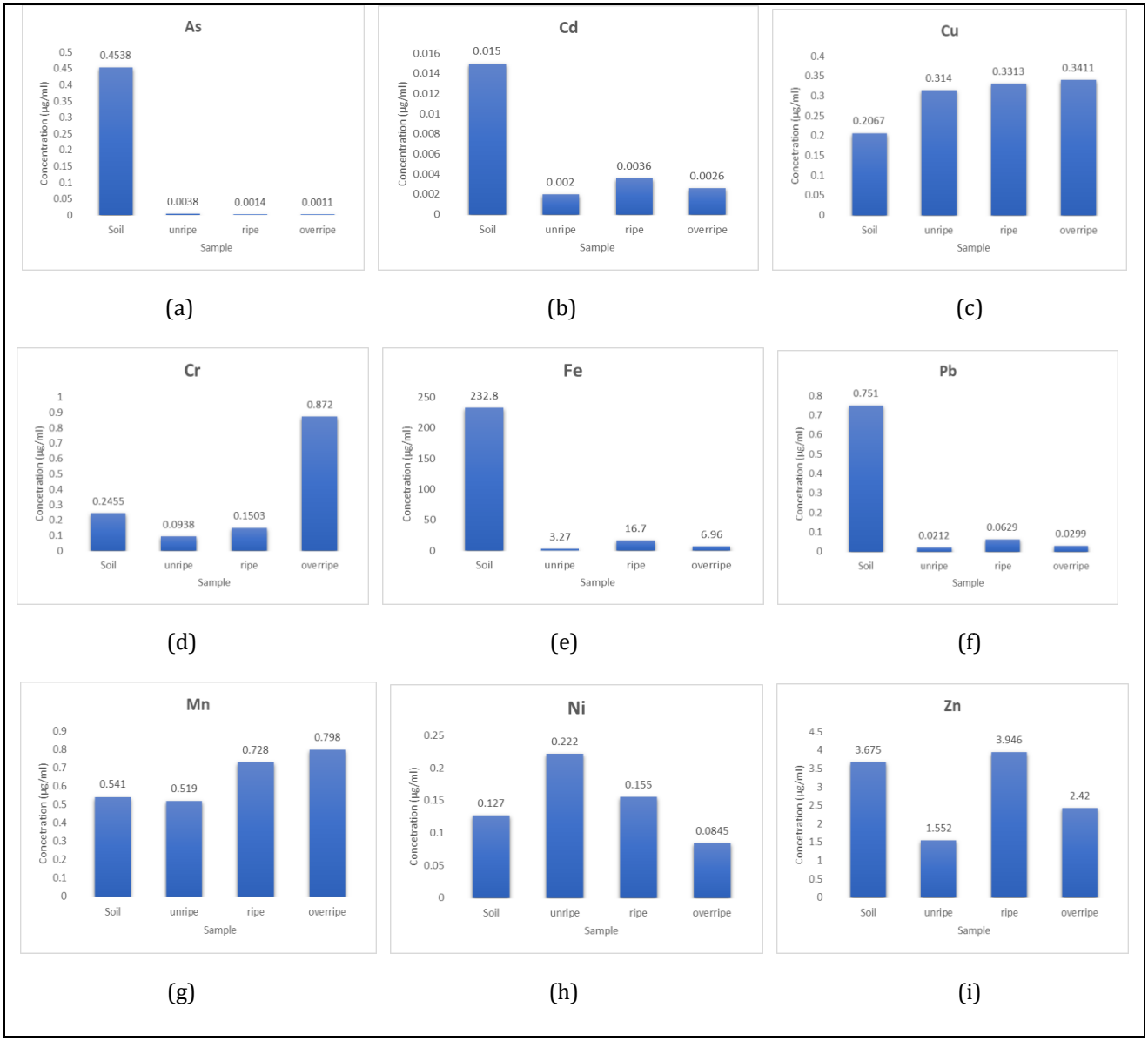

Fig. 1 Trace Elements Concentration in Soil and Saba Banana Samples

Fig. 1(b) shows that cadmium concentrations were highest in soil (0.0150 ± 0.0006 µg/mL), with ripe bananas showing slightly elevated levels (0.0036 ± 0.0001 µg/mL) compared to unripe (0.0020 ± 0.0001 µg/mL) and overripe bananas (0.0026 ± 0.0001 µg/mL). Cadmium absorption is influenced by factors like soil cation exchange capacity and plant transpiration rates [24,25]. The higher levels in ripe bananas may be due to enhanced nutrient uptake during peak ripening stages, as reported by [26]. All cadmium concentrations were below the Codex Alimentarius limit of 50 µg/mL, ensuring consumer safety.

Fig. 1(c) shows that copper levels increased progressively from soil (0.2067 ± 0.0049 µg/mL) to banana samples, with overripe bananas exhibiting the highest concentration (0.3411 ± 0.0116 µg/mL). Copper plays an essential role in enzymatic processes, such as ethylene biosynthesis during fruit ripening [27, 28]. The progressive accumulation aligns with findings by [29], who highlighted copper's role in enhancing ripening-associated metabolic activities. Despite this accumulation, all copper levels were significantly below the WHO permissible limit of 10,000 µg/mL, ensuring the bananas' safety for consumption.

Fig. 1(d) shows that chromium concentrations in soil (0.2455 ± 0.0051 µg/mL) exceeded those in banana samples, which showed increasing levels from unripe (0.0938 ± 0.0004 µg/mL) to ripe (0.1503 ± 0.0012 µg/mL) and overripe stages (0.8720 ± 0.0030 µg/mL). [30] reported that Cr content in banana fruits was 1.2 µg/mL (range 0.06–3.6 µg/mL), and [31] also observed 0.32 mg/kg Cr in banana, which was in line with the present study. This increase is consistent with observations by [32], who noted that ripening processes enhance chromium transport via altered membrane permeability. Additionally, soil conditions like redox potential influence chromium bioavailability, affecting uptake rates [27]. All chromium levels were below the FAO/WHO permissible limit of 2.300 µg/mL, confirming their safety.

Fig. 1(e) shows that iron concentrations were highest in soil (232.8000 ± 0.8800 µg/mL) and progressively increased in bananas from unripe (3.2700 ± 0.0500 µg/mL) to ripe (16.7000 ± 0.2900 µg/mL) before slightly declining in overripe bananas (6.9600 ± 0.1200 µg/mL). This pattern reflects the role of ferritin in iron storage and translocation during fruit development [33]. The significant decline in overripe bananas may result from redistribution to support cellular respiration. Despite low levels compared to the soil, all iron concentrations were well below the EFSA limit of 15,000 µg/mL, ensuring the bananas' safety.

Fig. 1(f) shows that lead levels were highest in soil (0.7510 ± 0.0030 µg/mL) and significantly lower in banana samples, with a peak in ripe bananas (0.0629 ± 0.0011 µg/mL). Lead accumulation is strongly influenced by soil pH and organic content, which regulate its bioavailability [16,25]. The slightly higher lead concentration in ripe bananas might result from increased nutrient transport during ripening [20]. These findings are consistent with those of [9], who noted that lead levels in fruits are generally lower than in soil, reflecting the plant's ability to limit lead uptake. All lead concentrations were below the Codex Alimentarius limit of 100 µg/mL, confirming that the fruit is safe for consumption.

Fig. 1(g) shows that manganese levels in soil (0.5410 ± 0.0010 µg/mL) were similar to those in unripe bananas (0.5190 ± 0.0020 µg/mL), with levels increasing significantly in ripe (0.7280 ± 0.0050 µg/mL) and overripe bananas (0.7980 ± 0.0040 µg/mL). This trend underscores manganese's role in photosynthesis and enzyme activation during ripening [22,19]. The observed manganese levels are comparable to those reported by [32], who found similar increases in manganese concentrations during the ripening of other banana varieties. Despite the observed increases, all manganese concentrations were below the [1] limit of 10,000 µg/mL, ensuring safety.

Fig. 1(h) shows that nickel concentrations were highest in unripe bananas (0.2220 ± 0.0010 µg/mL), followed by ripe (0.1550 ± 0.0020 µg/mL) and overripe stages (0.0845 ± 0.0008 µg/mL). Nickel absorption is influenced by soil mineral composition and the plant's physiological needs, as reported by [1]. The declining trend in later stages of ripening may reflect reduced metabolic demand. These findings align with those of [34], who noted that nickel levels in fruits are generally low and often below the detection limits in many cultivars. All nickel concentrations were significantly below the WHO limit of 12 µg/mL, confirming minimal health risks.

Fig. 1(i) shows that zinc levels peaked in ripe bananas (3.9460 ± 0.0080 µg/mL), followed by soil (3.6750 ± 0.0110 µg/mL), with lower levels in unripe (1.5520 ± 0.0070 µg/mL) and overripe bananas (2.4200 ± 0.0060 µg/mL). Zinc is critical for protein synthesis and hormonal regulation during ripening, as highlighted by [1]. [23] also found that Zinc concentration is among the highest between the trace elements which was 38.57 µg/mL indicates its important in fruit development. The observed levels were well below the FAO/WHO limit of 20,000 µg/mL, ensuring the fruit's nutritional contribution and safety.

3.2 Determination of Nutritional Value

Saba banana carbohydrate content changed significantly throughout ripening, as shown in Fig. 2(a). The carbohydrate content increased from 83.6 ± 1.2 g/100g in unripe bananas to a peak of 87.7 ± 1.3 g/100g at optimum maturity, before decreasing slightly to 85.7 ± 0.8 g/100g in overripe bananas. This trend aligns with earlier findings by [35], who observed similar starch hydrolysis into glucose and fructose during ripening in plantains. High manganese (Mn) levels enhance sugar metabolism and respiration, contributing to the observed decrease in overripe bananas [22]. This metabolic shift during ripening has also been reported in Cavendish bananas, although Saba bananas showed slightly higher carbohydrate retention, making them a superior energy source [17].

As shown in Fig. 2(b), Saba bananas' protein content steadily increased throughout ripening, starting from 4.413 ± 0.015 g/100g in unripe bananas to 4.770 ± 0.020 g/100g in ripe bananas, which was the highest among all ripening stages, before decreasing slightly to 4.540 ± 0.017 g/100g in overripe bananas. These values surpass those of standard banana cultivars, typically reported at 1.0–1.3 g/100g [16]. This increase is likely due to improved nitrogen absorption and protein synthesis during ripening [28]. The role of trace metals such as iron (Fe) and zinc (Zn) in enzyme and protein production during ripening further supports these findings [18]. Comparatively, Musa acuminata exhibits a similar but less pronounced trend, indicating Saba bananas' superior protein profile [19].

Enhanced Knowledge in Sciences and Technology Vol. 5 No.2 (2025) p. 353-361

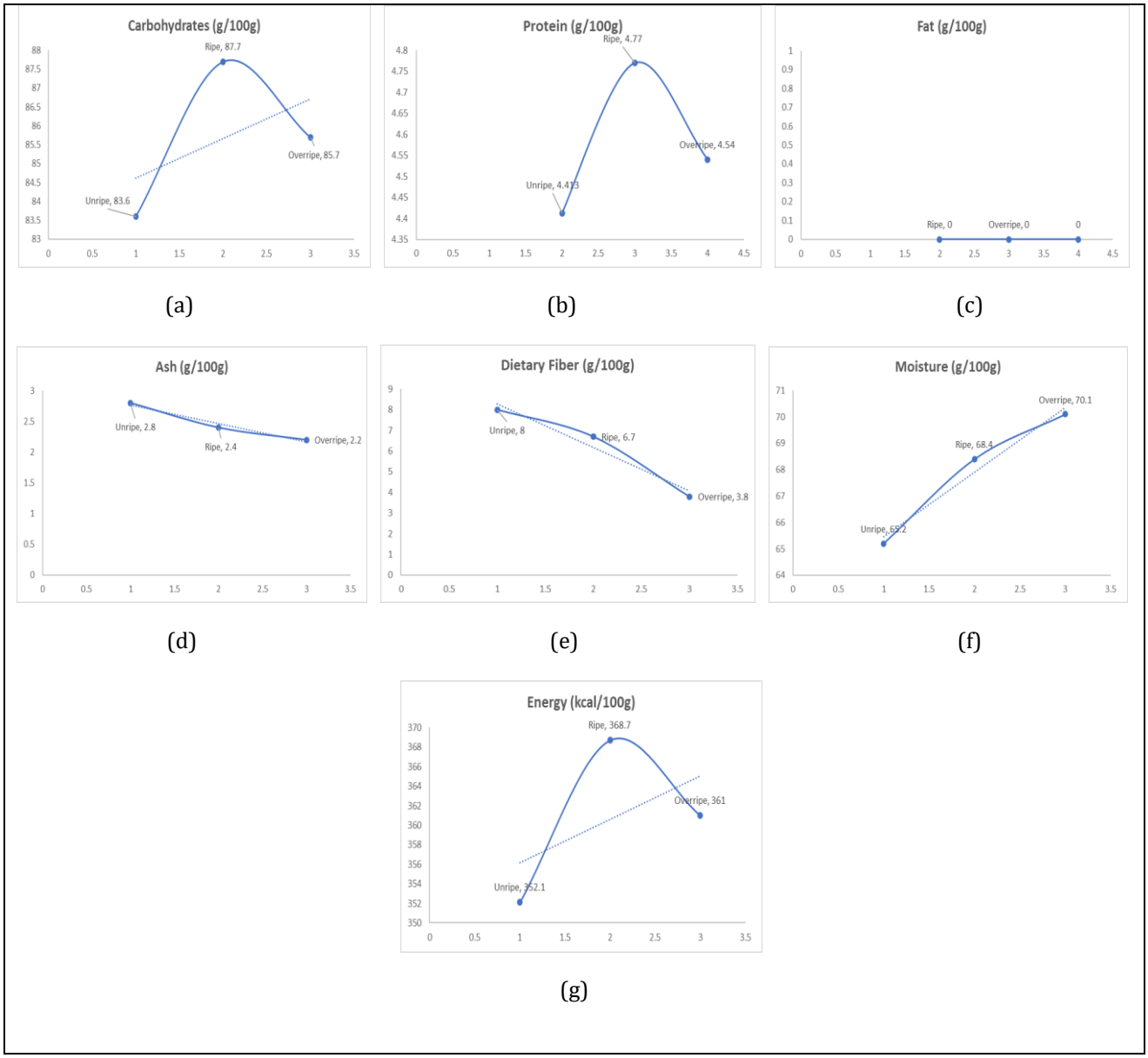

Fig. 2 Nutritional Content of Saba Banana Samples at Different Maturation Stages

Fig. 2(c) shows consistently low-fat content (<0.01 g/100g) across all ripening stages, reflecting Saba bananas' inherently low-fat profile. This result is consistent with bananas' reputation as a low-calorie fruit, as noted by [22]. The presence of chromium (Cr) in overripe bananas, which has a minor role in lipid metabolism, does not significantly impact the fat content, in line with findings by [35]. The stable fat content across ripening stages highlights bananas' suitability for low-fat diets, with potential applications in weight management and health-conscious food products [22]

As shown in Fig. 2(d), ash concentration in bananas decreased from 2.8 ± 0.1 g/100g in unripe bananas to 2.2 ± 0.1 g/100g in overripe bananas. This reduction is attributed to the redistribution of essential elements like iron (Fe) and manganese (Mn) during ripening, which supports the fruit's mineral absorption and utilization [24]. Increased moisture content during ripening also contributes to the dilution of ash content [17]. Similar trends have been observed in other banana varieties, such as Cavendish and Lakatan.

Fig. 2(e) highlights the highest fibre levels in unripe bananas (8.0 ± 0.2 g/100g), which are well above the average banana fibre content (2.6–3.0 g/100g)[1]. Fibre content declined progressively during ripening to 6.7 ± 0.3 g/100g in ripe bananas and 3.8 ± 0.2 g/100g in overripe bananas. The breakdown of pectin and cellulose during ripening explains this decline, as also noted by [32]. High manganese (Mn) levels influence lignin production and fibre integrity, further contributing to the observed pattern [19]. Compared to other banana cultivars, Saba bananas exhibit higher initial fibre levels, making them an excellent choice for dietary fibre enrichment [17].

The moisture content of Saba bananas increased steadily during ripening, from 65.2 ± 0.5 g/100g in unripe fruit to 70.1 ± 0.6 g/100g in overripe fruit, as shown in Fig. 2(f). This rise is attributed to the breakdown of starch into sugars, enhancing water retention, as previously observed by [28]. Potassium (K), an essential element for osmoregulation, likely played a role in this increase, although its levels were not quantified in this study [16]. The moisture dynamics during ripening are consistent with those observed in Cavendish bananas, but Saba bananas show higher final moisture content, potentially enhancing their textural appeal [22].

As shown in Fig. 2(g), the energy content of Saba bananas varied significantly throughout ripening, from 188.0 ± 2.1 kcal/100g in soil to 368.7 ± 2.9 kcal/100g in ripe bananas, before decreasing slightly to 361.0 ± 2.5 kcal/100g in overripe fruit. The high energy content in ripe bananas is attributed to the conversion of complex carbohydrates into simple sugars [19]. Compared to other cultivars like Gros Michel, which exhibit energy levels of 90–120 kcal/100g, Saba bananas provide a superior energy source, particularly for athletes and children [17]. The slight decline in overripe bananas aligns with increased respiration rates during late ripening stages [16].

3.3 Conclusion

In conclusion, this study demonstrates that Saba bananas are safe for consumption at all ripening stages, with trace elements such as arsenic and cadmium significantly decreasing as the fruit matures. Ripe bananas, in particular, offer notable nutritional benefits due to their high carbohydrate, protein, and energy content, making them an excellent dietary choice for sustained energy and muscle repair. The increase in essential elements like copper and manganese during ripening further enhances their nutritional value. These findings highlight the importance of monitoring trace elements to ensure food safety and optimize dietary benefits. Future research should investigate the mechanisms influencing trace element dynamics during ripening and explore strategies to enhance the nutritional value and safety of bananas, supporting sustainable agricultural practices and promoting healthier consumption habits.

Acknowledgement

The authors would like to thank the Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia, for its support.

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:*** *Nur Anisah Sahadi, Hatijah Basri;* ***data collection:*** *Nur Anisah Sahadi;* ***analysis and interpretation of results:*** *Nur Anisah Sahadi, Hatijah Basri;* ***draft manuscript preparation:*** *Nur Anisah Sahadi, Hatijah Basri. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] World Health Organization. (1996). Trace elements in human nutrition and health. World Health Organization. ISBN 92 4 156173 4, 72–309.
[2] Prasad, A. S. (2008). Zinc: Mechanisms of host defense. Journal of Nutrition, 138(5), 1445–1452.
[3] Beard, J. L. (2001). Iron biology in immune function, muscle metabolism and neuronal functioning. Journal of Nutrition, 131(2), 568S–579S.
[4] National Institutes of Health: Office of Dietary Supplements. (2019). Manganese. https://ods.od.nih.gov/factsheets/Manganese-HealthProfessional/
[5] Flora, S. J. S., Gupta, D., & Tiwari, A. (2012). Toxicity of lead: A review with special emphasis on the role of antioxidants. Environmental Toxicology and Pharmacology, 34(2), 451–460.
[6] Agency for Toxic Substances and Disease Registry (ATSDR). (2012). Toxicological profile for cadmium. U.S. Department of Health and Human Services.
[7] World Health Organization. (2011). Lead in drinking-water. In Background document for development of WHO guidelines for drinking-water quality.
[8] Kader, A. A. (2002). Postharvest technology of fruits. In Fruit and vegetable quality: A global perspective (pp. 1–10). University of California.
[9] Järup, L. (2003). Hazards of heavy metal contamination. British Medical Bulletin, 68(1), 167–182.
[10] Skoog, D. A., West, D. M., & Holler, F. J. (2014). Fundamentals of analytical chemistry (9th ed.). Cengage Learning.

[11] Islam, M. H., Nowar, A., Islam, S., Nayan, M. M., & Jubayer, A. (2024). A systematic review on heavy metals contamination in fruits and their associated health risks. Environmental Health Insights, 18, 11786302241309280.
[12] Dadzie, B. K., & Orchard, J. E. (1997). Routine post-harvest screening of banana/plantain hybrids: Criteria and methods. INIBAP Technical Guidelines 2. International Plant Genetic Resources Institute.
[13] Fan, Z., Fan, Z., Yan, F., Mo, L., Wang, T., Liao, J., ... & Fan, Y. (2013). Determination of 16 rare earth elements in banana by microwave digestion and ICP-MS. Agricultural Science & Technology, 14(11), 1583.
[14] Karasakal, A. (2021). Determination of major, minor, and toxic elements in tropical fruits by ICP-OES after different microwave acid digestion methods. Food Analytical Methods, 14, 344–360.
[15] Alzeer, M. (2024). Total carbohydrate by phenol-sulfuric acid method. In Nielsen's food analysis laboratory manual (pp. 147–151).
[16] Jain, V. M., Karibasappa, G. N., Dodamani, A. S., & Mali, G. V. (2017). Estimating the carbohydrate content of various forms of tobacco by phenol-sulfuric acid method. Journal of Education and Health Promotion, 6, 90.
[17] Magomya, A. M., Kubmarawa, D., Ndahi, J. A., & Yebpella, G. G. (2014). Determination of plant proteins via the Kjeldahl method and amino acid analysis: A comparative study. International Journal of Scientific and Technology Research, 3(4), 68–70.
[18] Dennis, G., & Kazuhiro, O. (2002). Determination of total dietary fiber in selected foods containing resistant maltodextrin by enzymatic-gravimetric method and liquid chromatography: Collaborative study. Journal of AOAC International, 85(2), 435–444.
[19] Geeth, H., Dilini, N. P., Senevirathne, N., & Indira, W. (2020). Extraction methods of fat from food samples and preparation of fatty acid methyl esters for gas chromatography: A review. Arabian Journal of Chemistry, 13(8), 6886–6887.
[20] Castillo, C., García, G., Hernández, A., & Zamora, M. (2019). Proximate composition and energy value analysis of five varieties of malting barley. International Journal of Food Science and Biotechnology, 4(2), 35–39.
[21] Sinha, D., Datta, S., Mishra, R., & Agarwal, P. (2023). Negative impact of arsenic on plants and mitigation strategies. Plants, 12(9), 1–46.
[22] Shaaria, N. E. M., Tajudin, M. T. F. M., Khandaker, M. M., Majrashi, A., Alenazi, M. M., Abdullahi, U. A., & Mohd, K. S. (2021). Cadmium toxicity symptoms and uptake mechanism in plants: A review. Brazilian Journal of Biology, 7–8.
[23] Islam, M. S., Islam, M. T., Ismail, Z., Islam, A. R. M. T., Khan, R., Hasan, F., ... & Idris, A. M. (2023). Assessment of trace elements in the long-term banana cultivation field's soil. Frontiers in Environmental Science, 11, 2296–665X.
[24] Riyazuddin, N., Bushra, E., Iqbal, K., Kumar, M., Ramteke, P. W., & Gupta, R. (2021). A comprehensive review on the heavy metal toxicity and sequestration in plants. Biomolecules, 12(1), 43.
[25] Hooda, P. (2010). Assessing bioavailability of soil trace elements. In Trace elements in soils (pp. 227–265).
[26] Ullah, H., Shah, A., Ali, H., Jan, F. A., & Khan, S. (2020). Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. Journal of Water Supply: Research and Technology – AQUA, 69(1), 36–50.
[27] Abdullahi, N., Igwe, E. C., & Dandago, M. A. (2021). Heavy metal uptake and stress in food crops: A review. FUDMA Journal of Sciences, 5(1), 323–332.
[28] Andresen, E., Peiter, E., & Küpper, H. (2018). Trace metal metabolism in plants. Journal of Experimental Botany, 69(5), 909–954.
[29] Cao, X., Wen, Z., Shang, C., Cai, X., Hou, Q., & Qiao, G. (2020). Copper amine oxidase (CuAO)-mediated polyamine catabolism plays potential roles in sweet cherry (Prunus avium L.) fruit development and ripening. International Journal of Molecular Sciences, 23(20), 12112.
[30] Islam, M. S., Ahmed, M. K., Al-Mamun, M. H., & Raknuzzaman, M. (2015). The concentration, source and potential human health risk of heavy metals in the commonly consumed foods in Bangladesh. Ecotoxicology and Environmental Safety, 122, 462–469.
[31] Shaheen, N., Irfan, M. N., Khan, I. N., Islam, S., Islam, M. S., & Ahmed, M. K. (2016). Presence of heavy metals in fruits and vegetables: Health risk implications in Bangladesh. Chemosphere, 152, 431–438.
[32] Sharma, A., Kapoor, D., Wang, J., Shahzad, B., Kumar, V., Bali, A. S. & Yan, D. (2020). Chromium bioaccumulation and its impacts on plants: An overview. Plants, 9(1), 100.
[33] Sun, J., Yu, Z., Wang, Y., Lee, J., Jung, J., & Jeon, J. (2022). Minireview: Chromatin-based regulation of iron homeostasis in plants. Plants, 13(1), 1.
[34] Alloway, B. J. (2013). Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability (3rd ed.). Springer.
[35] Ranjha, M., Modassar, I., Shafeeqa, I., Nadeem, M., & Mahmood, S. (2022). A comprehensive review on nutritional value, medicinal uses, and processing of banana. Food Reviews International, 38, 199–225.