

## The evaluation of the physicochemical properties of bananas (*Musa acuminata*) coated with different polysaccharide-based coating

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### Abstract

Bananas are among the most important fruits in global trade. However, bananas have a short shelf life which results in financial losses for farmers and can lead to food waste. Therefore, developing an edible coating for bananas may help to extend their shelf life and reduce food waste. Researchers have explored diverse composite combinations of edible coating including polysaccharide, protein and lipid-based coating. However, protein and lipid-based coating have very low permeability to oxygen. This leads to anaerobic respiration of the fruit which causes unpleasant flavours and alters the texture. The polysaccharide-based coating offers advantages that exhibit semi-permeability to moisture, thereby diminishing oxygen absorption, lowering carbon dioxide and ethylene emission from fruits, mitigating microorganism attacks, and ultimately prolonging the shelf life of the produce. However, limited research tested the effect of the physicochemical properties of the coated fruit, especially bananas. Thus, an edible coating combining polysaccharide-based (alginate, carrageenan and pectin) and ZnONPs for bananas was developed. The bananas were dipped in the formulations produced; AlZnONPs, CZnONPs, PZnONPs and R (uncoated). The coated bananas were stored at room temperature for 15 days to observe the physicochemical changes (weight loss, total soluble solids, total acidity, pH, reducing sugar and firmness) that happened. The physicochemical properties of the coated bananas were significantly different ( $P < 0.05$ ) between the coated and uncoated bananas with the increased storage time. Coated bananas were found to have significant changes in their physicochemical properties. These findings offer a potential for post-harvest technologies that could increase income for farmers and reduce food waste. This polysaccharide-based coating should be tested on other types of food that could benefit local farmers.

## 1. Introduction

Bananas, scientifically referred to as *Musa* spp., have a prominent global trade position due to their extensive consumption, economic value, and contribution to livelihoods (Mahmud *et al.*, 2022). Bananas rank as the fourth most crucial crop worldwide (Pongprasert *et al.*, 2021). This crop's substantial export value significantly benefits economies and offers livelihoods to farmers and labourers across the supply chain (Qin *et al.*, 2023). Bananas, rich in nutrients like potassium and fibre, are

staple foods globally, ensuring steady demand (Munia *et al.*, 2019). With its favourable climate, Malaysia also participates in the global banana trade. Malaysia cultivates diverse banana varieties for local and international markets, contributing to its economy and food industry. However, bananas have a short shelf life of 7 days which results in financial losses for farmers and can lead to food waste (Tkáč *et al.*, 2022). Therefore, developing an edible coating for bananas may help to extend their shelf life up to 15 days (Panariello *et al.*,

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2022). There are various studies on formulating the edible coating solution that was proven to extend the shelf life of foods (Kong *et al.*, 2022). Researchers have explored diverse composite combinations of edible coating including polysaccharide, protein, and lipid-based coating. Nevertheless, coatings made from proteins and lipids exhibit minimal oxygen permeability, leading to anaerobic respiration in fruits. This, in turn, results in undesirable flavours and changes in texture. Numerous studies have explored the development of edible coating solutions, including those based on polysaccharides, which have demonstrated the ability to extend the shelf life of various foods. The advantage of polysaccharide-based coatings lies in their semi-permeability to moisture, effectively reducing oxygen absorption, minimizing carbon dioxide and ethylene emissions from fruits, preventing microbial attacks, and ultimately prolonging the shelf life of the produce. Despite these benefits, there is a scarcity of research examining the impact of physicochemical properties on coated fruits, particularly bananas.

Thus, a newly combined polysaccharide-based (alginate, carrageenan and pectin) and ZnONPs for bananas was developed. The utilization of polysaccharides as biopolymers in creating edible film coatings is driven by their effective oxygen barrier properties due to strong hydrogen bonds leading to organised structures (Song *et al.*, 2021). Polysaccharides such as cellulose, pectin, carrageenan, alginate, starch, chitin, and chitosan replace traditional packaging materials, aligning with sustainability trends. These coatings, often transparent and oil-free (de Oliveira *et al.*, 2021), prolong fruit shelf life by preventing microbial growth while maintaining aerobic conditions (Ilyas *et al.*, 2022). Alginate, derived from marine brown algae, serves as a stabilizer and thickener in the food industry. It is applied as a coating to slow fruit ripening, involving immersion in alginate solutions containing glycerol and calcium chloride (Bibi *et al.*, 2023). Carrageenan, from red algae, forms coatings that alter fruit atmospheres, extending shelf life. Kappa-carrageenan, approved by the FDA, is used in edible coatings to reduce respiration rates, maintain firmness, delay ripening, and improve fruit quality (Smola-Dmochowska *et al.*, 2023). Pectin, derived from plant cells, is a soluble fibre rich in galactose, arabinose, and rhamnose. Sourced from fruits like apples and citrus, pectin is used as an edible coating that effectively protects fruits by offering barriers against oxygen and carbon dioxide (Menezes and Athmaselvi, 2016).

Zinc oxide nanoparticles were added to the formulation due to the properties of antibacterial, antimicrobial, and UV-blocking properties (Jiang *et al.*,

2018). In an investigation by La *et al.* (2021), it was determined that the optimal concentration for creating a uniform layer on banana peels within edible coatings was 0.5% ZnONPs. In this study, the bananas were dipped in the formulations produced; AlZnONPs, CZnONPs, PZnONPs and R (uncoated). The coated bananas were stored at room temperature for 15 days to observe the physicochemical changes (weight loss, total soluble solid, titratable acidity, pH, reducing sugar and firmness) that happened. Coated bananas were found to have significant changes in their physicochemical properties and these findings offer excellent potential in post-harvest technologies that could increase income for farmers and reduce food waste and food waste management.

## 2. Materials and methods

### 2.1 Materials

Bananas (*Musa acuminata*) with a maturity index of 1 were obtained from a banana plantation in Kampung Acheh, Kuala Pilah (Axes Agro Sdn Bhd). The bananas were also free from physical and microbiological appearance damage. The bananas were washed using distilled water and dried at room temperature before use. Cassava starch (Cap Kapal ABC, Malaysia), alginate, kappa-carrageenan and pectin (Evachem, Malaysia) were also obtained from the local market. The chemicals used were food-grade zinc oxide nanoparticles (US Research Nanomaterials Inc., USA), glycerol (Sigma-Aldrich, Germany), sodium hydroxide (RandM Chemicals, Malaysia), phenolphthalein (RandM Chemicals, Malaysia) indicator and DNS standard (Sigma-Aldrich, USA). All substances are chemical grade and used without further purification.

### 2.2 Preparation of polysaccharide-based coating solution

Briefly, two solutions are prepared namely solution A and solution B. For solution A, 1.0 g (0.5%) of zinc oxide was added to 80 mL of distilled water. The solution was stirred until dissolved by constant stirring using a water bath sonicator for 10 mins. For solution B, the 2.0 g of alginate was weighted to produce 1.0%, then the alginate was mixed with 80 of distilled water and stirred at 50°C for about 30 mins using a magnetic stirrer. After 30 mins, 1.0 g (0.5%) of glycerol is added into solution B to support binding with zinc oxide solution. Finally, solutions A and B are mixed with the addition of 40mL of distilled water and stirred for 2 hrs to produce an AlZnONPs coating solution (Bahrami *et al.*, 2019; Eldib *et al.*, 2020). The solution was allowed to be cooled at 28°C or room temperature before applying banana coating. The procedure was repeated by replacing the alginate with carrageenan (CZnONPs) and

pectin respectively (PZnONPs).

### 2.3 Physicochemical analysis of the coated banana determination of weight loss

The measurement of banana weight reduction was conducted utilising a digital balance (Adam Equipment's PGW precision balance, UK). The initial weighing of the bananas was done at the onset of storage (W0). Throughout the storage period, the bananas were weighed every three days at 9 am in the morning (W1). The experimental procedure was replicated three times for each treatment (Saekow *et al.*, 2019). The percentage of weight loss (%) was determined using the subsequent formula:

$$\text{Weight loss (\%)} = (W0 - W1) / W0 \times 100$$

### 2.4 Determination of total soluble solids

The measurement of total soluble solids (TSS) in bananas was conducted using a portable refractometer. A total of 10g of banana flesh was mixed with 100 ml of distilled water. The resultant juice was subjected to filtration through a vacuum filter. The filtrate was then utilised to ascertain the TSS content. The outcomes were denoted in °Brix units. The experimental protocol entailed assessments performed every three days, with triplicate repetitions for each treatment (Wani *et al.*, 2021).

### 2.5 Determination of total acidity

The determination of total acidity (TA) in bananas was carried out through the titration method. A quantity of 10g of banana flesh was blended with 100 ml of distilled water. The resulting juice underwent filtration utilising a vacuum filter. The filtrate was utilised for the assessment of TA. For this purpose, 10mL of the filtrate was mixed with 1% phenolphthalein indicator and titrated with a solution of 0.1 N NaOH. The appearance of a colour change in the indicator signified the endpoint. The TA content was expressed as a percentage of malic acid. The experimental procedure involved conducting trials every three days, with three replicates for each treatment (Nguyen *et al.*, 2021). The calculation for titratable acidity (%) is as follows:

$$\text{Titratable acidity (\%)} = [V(\text{NaOH}) (\text{mL}) \times C(\text{NaOH}) (\text{N}) \times 0.067 \times 100] / 10 \text{ g}$$

Where V(NaOH) represents the volume of NaOH solution in mL, C(NaOH) is the molarity of the NaOH solution, and 0.067 is the conversion factor for malic acid.

### 2.6 Determination of pH value

The measurement of pH in bananas was conducted employing a digital pH meter (765 Laboratory pH meter, Europe). A portion of 10 g of banana flesh was combined with 100 mL of distilled water. The resultant juice was subjected to filtration using a vacuum filter. The filtrate was then utilised to establish the pH value. The experimental schedule involved assessments performed every three days, with triplicate repetitions for each treatment (Wani *et al.*, 2021).

### 2.7 Determination of reducing sugar

The measurement of reducing sugar was determined by using a UV/Vis double-beam spectrophotometer. Firstly, the filtrate sample was mixed with distilled water and diluted, followed by the preparation of glucose standard solutions at various concentrations. DNS reagent was added to each sample, and absorbance was measured. Distilled water was added to the tubes, and the mixture was analysed at a maximum wavelength (490 nm) using a UV/Vis double-beam spectrophotometer for both standard and sample solutions.

### 2.8 Determination of firmness

The assessment of banana firmness was conducted employing a texture analyser (Stable Micro Systems, England). The bananas were subjected to penetration to a depth of 5 mm using a 2 mm cylindrical probe, with a penetration rate of 5 mm/s. The measurement recorded was the peak penetration force (N). The experimental procedure involved conducting evaluations every three days, with triplicate repetitions for each treatment (Saekow *et al.*, 2019).

### 2.9 Statistical analysis

The data for physicochemical analysis was expressed in the mean and standard deviation. The mean values were evaluated by using a one-way ANOVA ( $p < 0.05$ ) to evaluate the significant difference between samples. The analysis was determined using SPSS Inc Software (Version 24).

## 3. Results and discussion

### 3.1 Determination of weight loss

Weight loss is an important aspect to consider when evaluating the effectiveness of the coating in prolonging the shelf life and quality of the fruit. In this study, Figure 1 illustrates the trend of percentage weight loss over 15 days for coated (AlZnONPs, CZnONPs, PZnONPs) and uncoated bananas (R). All treatments exhibit a general increasing trend over time. The R sample steadily increased throughout the period. CZnONPs initially rose

until day 6, spiked significantly at day 12, and had a slight increase again towards the end; AlZnONPs demonstrated a steady rise with a slight acceleration around day 9, while PZnONPs consistently increased but at a slower rate towards the later days. Overall, there are significant differences ( $p < 0.05$ ) between the coated and uncoated bananas in terms of weight loss. Edible coatings act as an extra layer that coats the stomata and guard cells, forming a film on the surface of the fruit (Tumbariski *et al.*, 2019). This extra layer created by the coating serves to reduce respiration and transpiration in the fruit, ultimately resulting in reduced moisture loss and gaseous exchange from the bananas (Zhou *et al.*, 2021).

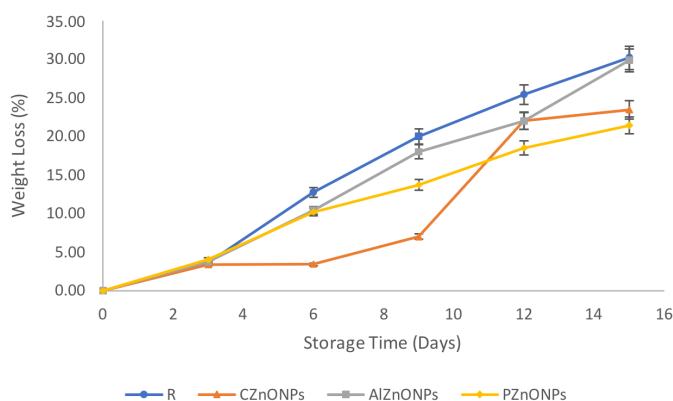


Figure 1. The weight loss (%) of uncoated and coated bananas for 15 days of storage at room temperature.

Various studies have shown the same results that alginate coatings have a positive effect on preventing weight loss in plum, sweet cherry, and apple fresh cuts (Korbecka-Glinka *et al.*, 2022), indicating their potential efficacy in preserving the quality of bananas as well. One study specifically focused on the effect of alginate coatings on weight loss in bananas, using a combination of sodium alginate, ascorbic acid, olive oil, and citric acid as the coating materials (Solís-Contreras *et al.*, 2021). This study found that the treatment of 3% calcium alginate proved to be the most efficient in reducing weight loss in bananas, followed by a treatment of 3% sodium alginate.

The use of carrageenan-based coatings on bananas has been found to have a significant effect on reducing weight loss (Dwivany *et al.*, 2020). The use of carrageenan-based coatings on bananas has been found to have a significant effect on reducing weight loss (Dwivany *et al.*, 2020). Dwivany *et al.* (2020) reported that weight loss reduction in fresh-cut banana fruits was achieved by combining calcium chloride with carrageenan coating. Previous research on coated mangoes demonstrated that pectin coatings can significantly decrease weight loss compared to untreated fruits after 6 days of storage at room temperature (Abdelaziz *et al.*, 2022). A study by Placido *et al.* (2018)

demonstrated that coating mangaba fruits with pectin biofilms increased their shelf life (Chandel *et al.*, 2022). Overall, the use of polysaccharide-based coatings for banana preservation has been studied and shown promising results in extending the shelf life and maintaining the quality of bananas.

### 3.2 Determination of firmness

Fruit firmness is an important quality attribute that greatly affects consumer preference and post-harvest handling techniques (El-Beltagi *et al.*, 2022). In this study, Figure 2 illustrates the trend of firmness over 15 days for coated (AlZnONPs, CZnONPs, PZnONPs) and uncoated bananas (R). All treatments exhibit a general decreasing trend in firmness over time, indicating that the substances become less firm as the storage days increase. All treatments exhibit a general decreasing trend in firmness over time, indicating that the substances become less firm as the storage days increase. The firmness of R consistently decreases over the entire period. CZnONPs continued to decrease; AlZnONPs and PZnONPs both showed a steady decline in firmness over the days. From the trend, there was significant differences ( $p < 0.05$ ) between the coated and uncoated bananas in terms of weight loss.

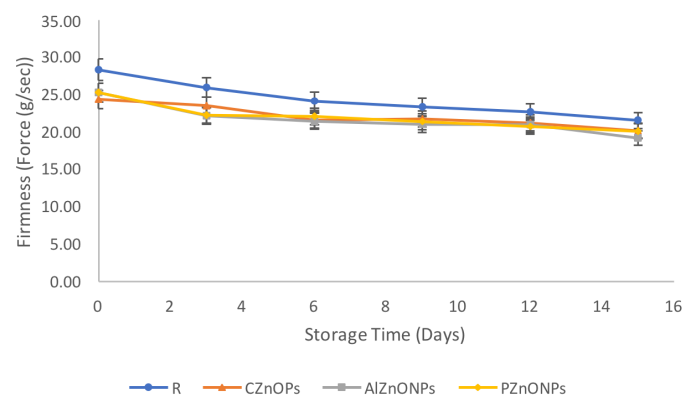


Figure 2. The firmness of uncoated and coated bananas for 15 days of storage at room temperature.

Alginate-based coatings have been shown to extend or enhance the firmness of fruits by creating a protective barrier that inhibits moisture loss and minimises the degradation of cell walls (Mahmoud *et al.*, 2022). Additionally, the protopectin in the peels and pulp of bananas can be transformed into soluble pectin due to the presence of an enzyme called protopectinase, which leads to a decrease in firmness during storage (Ma *et al.*, 2019). Therefore, utilising an alginate-based coating on bananas may also inhibit the activity of protopectinase and prevent the conversion of protopectin into soluble pectin, thereby maintaining the firmness of the fruit. In addition to the alginate-based coating, other factors such as the presence of calcium chloride have also been shown to contribute to maintaining the firmness of coated bananas (Baite *et al.*, 2022).

Research has shown that carrageenan-based coatings can modify the internal gas composition of fruits, specifically reducing oxygen concentrations and increasing carbon dioxide concentrations (Dwivany *et al.*, 2020). This modification of the atmosphere surrounding the fruit can slow down textural changes and help maintain firmness (Hassan *et al.*, 2022). The study found that the firmness of strawberries decreased over time during storage, as expected. However, the strawberries coated with carrageenan-based coatings exhibited higher levels of firmness compared to the control samples (Solís-Contreras *et al.*, 2021). The ability of carrageenan to form a barrier between the fruit and the surrounding gas has been proven effective in reducing respiration and minimising discolouration in fresh-cut fruit (Warsiki and Manan, 2022). Additionally, carrageenan films can provide antibacterial protection and maintain fruit texture during storage (Smola-Dmochowska *et al.*, 2023).

The pectin-based coating helped to slow down the decrease in firmness of the bananas over time (Felicia *et al.*, 2022). This can be attributed to the fact that the pectin-based coating acts as a barrier, preventing the degradation of the cell wall and the transformation of starch, polysaccharides, hemicelluloses, and pectin into sugars during the maturation process (Sun *et al.*, 2022). In addition to the protective function of the pectin-based coating, other compounds such as nanocellulose and sucrose ester fatty acid were also found to contribute to the firmness retention of coated bananas (Cárdenas-Barboza *et al.*, 2021). Overall, the findings from various studies suggest that coating bananas with polysaccharide-based coatings can positively impact their firmness and postharvest quality (Soleh *et al.*, 2022).

### 2.3 Determination of total soluble solids

TSS is an important method to evaluate the concentration of dissolved solids, especially sugars, organic acids and other soluble compounds in fruit. Analysis of TSS also can be used to determine the maturity of the fruit. The more mature the fruit, the higher the TSS levels in fruits as they ripen due to the production of sugar content which leads to fruit sweetness (Emam *et al.*, 2021). In this study, Figure 3 illustrates the trend of firmness over 15 days for coated (AlZnONPs, CZnONPs, PZnONPs) and uncoated bananas (R). All treatments show notable changes from day 6 onwards. R sharply ascends, peaks at day 12, and plateaus, while AlZnONPs rise from day 9, stabilising by day 12; CZnOPs and PZnONPs both begin increasing on day 12, with PZnONPs showing a steeper climb, suggesting potential for further growth by the end of the 15 days.

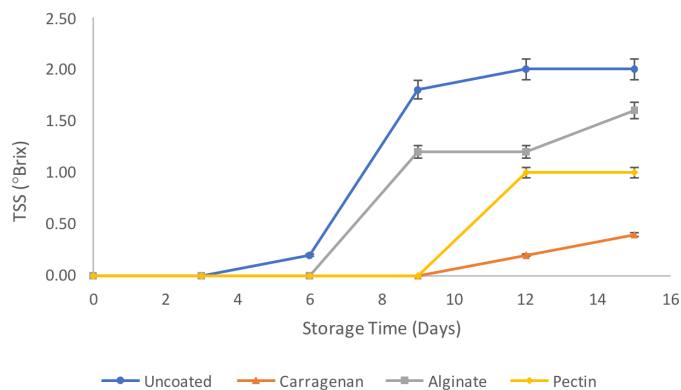


Figure 3. The TSS of uncoated and coated bananas for 15 days of storage at room temperature.

This increase in TSS is a significant measure related to consumer taste preference, with fruits above 12% Brix being considered more acceptable to consumers (Siriwardana *et al.*, 2017). As stated by Yang *et al.* (2021), unripe bananas have a high fibre content but low sugar content. After undergoing the ripening phase, the sugar content in bananas will be high in sugar and the fibre content will be low where it is suitable for consumption. Therefore, sugar content plays an important role as a basic component in fruits considering the sweetness of the fruit influences customer satisfaction with consumption of bananas.

According to Maftoonazad *et al.* (2019), the ripening of fruits is influenced by the interaction of starch and amylase. Starch is a complex carbohydrate found in plant tissues that store energy. Amylase enzyme degrades starch into simpler sugars (glucose, fructose and sucrose), which contributes to the sweetness of the fruit. Therefore, this phenomenon described the increasing pattern in TSS value for uncoated bananas. This situation demonstrates the outcome mentioned by (Thakur *et al.*, 2019) when an edible coating is applied on fruit like apples, papaya and strawberries. Hence, coated bananas had a lower TSS value than uncoated bananas. According to Suhaimi *et al.* (2021), a low rate of respiration influences the TSS value, hence resulting in a low TSS content of coated banana during storage. The incorporation of ZnONPs into the alginate-based coating also prevents strawberry TSS from increasing (Emamifard and Bavaisi, 2020).

### 2.4 Determination of total acidity

TA is a key metric for assessing the quality and ripeness of coated fruits. It measures the total acid content in a fruit, influencing its flavour and sensory attributes. TA is often expressed using standard solutions like citric or malic acid, and the measurement is typically done using titration. In this study, Figure 4 illustrates the trend of TA over 15 days for coated (AlZnONPs, CZnONPs, PZnONPs) and uncoated bananas (R). Over

the 15 days, all treatments initially start with identical values, but R consistently declines more than AlZnONPs. CZnOPs exhibit a gradual decline, aligning closely with PZnONPs by day 15, and all treatments seem to converge toward similar values by the end of the observation period, with AlZnONPs lagging slightly.

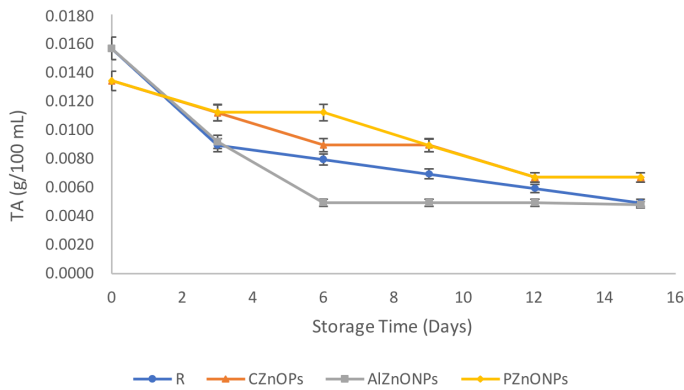


Figure 4. The TA of uncoated and coated bananas for 15 days of storage at room temperature.

Research by Thakur *et al.* (2018) and Wani *et al.* (2021) highlights that coated fruits have higher TA than uncoated ones because of natural ripening and the involvement of organic acids in the fruit's respiratory process. Based on findings, it is reported that the TA for the uncoated decreased at a faster rate compared to the coated banana as the uncoated fruits encounter a natural ripening process due to the presence of malic acid that decreases along with the production of sugar in fruit flesh, therefore the banana undergoes physical and chemical changes where the degradative process is higher (Meindrawan *et al.*, 2018). According to earlier research, as storage time increased, the TA of apples was significantly reduced (Sarduni *et al.*, 2020). Furthermore, both uncoated and coated fruits' TA were reduced as storage time was extended (Bakhy *et al.*, 2018). According to Bakhy *et al.* (2018), fruit ripening and senescence were evidenced by the decrease in organic acid concentration and lowering of acidity during the storage period.

According to Hmam *et al.* (2023), the TA of all the mango samples had a significant decrease from 10.35 to 11.31% at the beginning of the storage period to 2.56 and 3.79, respectively, under uncoated and alginate treatments. Also, uncoated strawberries showed a far higher range in TA values after storage than coated samples (Emamifar and Bavaisi, 2020). The TA value of uncoated bananas decreased rapidly over the storage period. However, the addition of ZnONPs to the chitosan and Arabic gum coating slows the TA value rate of bananas over 17 days of storage (La *et al.*, 2021). The study by Rosman *et al.* (2022) also reported the slowing rate of TA across time by using glutinous tapioca starch and zinc oxide nanoparticles (Rosman *et al.*, 2022).

Research by Tabassum and Khan (2020) also showed that the TA value of uncoated fresh-cut papaya showed a drastic decrease while the coated samples gradually decreased over the storage time.

### 2.5 Determination of pH value

pH analysis is a critical parameter for determining the concentration of hydrogen ions in a fruit-content solution and evaluating the relationship between the coating and the acidity or alkalinity of fruits (Suhaimi *et al.*, 2021). Furthermore, pH analysis aids in determining the impact of the coating on the acidity of the fruit and provides insight into safety criteria, quality, and overall shelf life of coated fruit. Coating effectiveness on the pH of coated fruits is where it can act as a barrier against external factors and gas exchange such as oxygen and carbon dioxide (Wani *et al.*, 2021). As a result, the coating can preserve the natural acidity of the fruit content by reducing moisture loss and pH changes (Meindrawan *et al.*, 2018). Figure 5 depicts the progression of four treatments over 15 days. All treatments consistently show upward trends, with R demonstrating steady linear growth and CZnOPs experiencing a more pronounced increase, maintaining a slight lead over PZnONPs. AlZnONPs exhibit a gradual ascent, aligning closely with CZnOPs by the end, indicating synchronised growth and potential correlation in behaviours or shared influencing factors among the treatments.

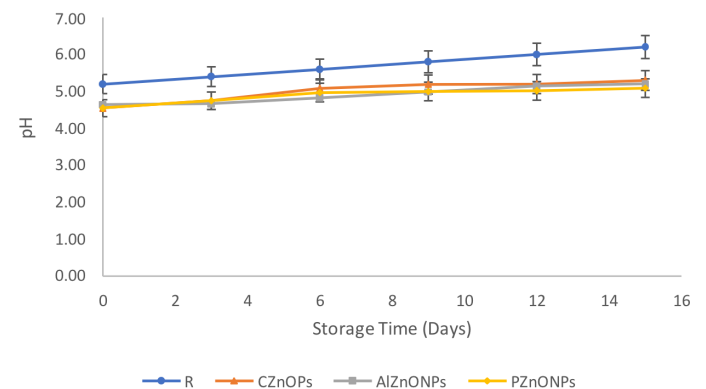


Figure 5. The pH of uncoated and coated bananas for 15 days of storage at room temperature.

According to Dwivany *et al.* (2020), pH is a measure of the concentration of hydrogen ions which indicates the acidic or alkaline of the intended food. Hence, pH analysis acts as an indicator to ensure coating can maintain the desirable pH value of fruits. The ripening process of bananas was influenced by an increase in respiration rate, and a reduction of organic acid and ethylene production, which is a compound involved in fruit ripening. This compound affects the ripening process and can lead to banana senescence when stored for an extended period. As a result, this phenomenon will

eventually result in an increase pH value of the banana. According to Suhaimi *et al.* (2020), organic acids are reduced during fruit ripening because most of the acids are used in the respiration process and converted to sugar. A higher rate of production of the compound will increase the concentration of OH- resulting higher pH of uncoated banana. Overall, the coating method has demonstrated the ability to prolong the climacteric and metabolic rate of banana ripening, thereby reducing acid intake during the respiration process. When the fruits were kept in storage for prolonged periods, senescence occurred because of that the pH would gradually increase (Suhaimi *et al.*, 2021).

Slow respiration rate due to lower pH value changes (Sarduni *et al.*, 2020). Fruits contain organic acids, which are used as substrates for enzyme processes during respiration (Sarduni *et al.*, 2020). Sarduni *et al.* (2020) mentioned in their study that by applying an edible coating to fruits, it is possible to slow down the rate of respiration while preventing organic acids from interacting with enzymatic reactions that occur during respiration. According to this study, bananas generally have a pH range of 4.55 to 5.30. When the fruits were kept in storage for prolonged periods, senescence occurred because of that the pH would gradually increase (Suhaimi *et al.*, 2021).

Bananas contain organic acids including citric acid and malic acid, which are used as substrates for enzyme processes during respiration. Sarduni *et al.* (2020) mentioned in their study that by applying an edible coating to fruits, it is possible to slow down the rate of respiration while preventing organic acids from interacting with enzymatic reactions that occur during respiration. According to Sarduni *et al.* (2020), the pH of the 2% (w/v) and 3% (w/v) coated banana samples is lower than that of the uncoated samples, even though the differences are not statistically significant between the two different levels of pectin edible coating.

Meanwhile, the pH of the uncoated papaya cubes was the highest at 6.1, followed by the alginate-coated sample at 5.93 (Tabassum and Khan, 2020). However, research by Dulta *et al.* (2022) confirms that pH values are unaffected by the type of edible coating, storage temperature, or storage period. During the respiration of bananas, organic acids like citric acid and malic acid were used as substrates for the enzymatic reactions. These phenomena resulted in an increase in pH value as the organic acid content in the banana decreased throughout the storage period (Sarduni *et al.*, 2020). The properties of alginate act as a good barrier to oxygen, which may limit the organic acid's breakdown. Usually, as the TA decreases, the pH value increases.

## 2.6 Determination of reducing sugar

Reducing sugars has a significant impact on the flavour, sweetness, and overall quality of fruits. The presence and concentration of reducing sugars become important factors to consider when fruits are coated with edible coatings. Reducing sugars such as glucose and fructose are carbohydrates that could reduce certain chemicals and participate in chemical reactions (Pavinatto *et al.*, 2020). Glucose and fructose are classified as reducing sugars due to the presence of a free aldehyde or ketone group that can undergo oxidation reactions. Thus, the use of coatings on fruit can affect the concentration and distribution of reducing sugars in cases where the coating acts as a physical barrier, preventing the fruit from external factors such as transpiration of moisture and bacterial contamination. As a result, this barrier can help maintain the fruit's moisture content, potentially lowering sugar levels. Figure 6 illustrates the trajectories of four treatments over 15 days, all showing an increasing trend. Initially, R and AlZnONPs start similarly, while CZnONPs and PZnONPs lag slightly. Around days 12-15, there is a significant simultaneous increase, with R leading, and by the end, the treatments converge, indicating synchronised influences or related behaviours. The overall pattern indicates significant differences ( $p < 0.05$ ) between the coated and uncoated samples.

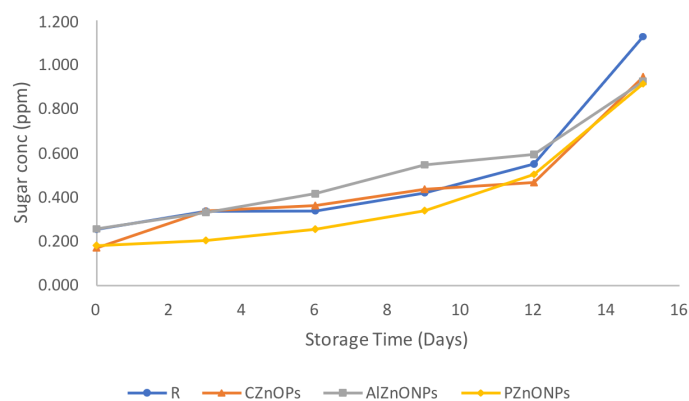


Figure 6. The reduced sugar of uncoated and coated bananas for 15 days of storage at room temperature.

According to Sucheta *et al.* (2019), the starch in the banana is converted into sugar during the ripening phase. However, the banana's respiration function continuously consumes this produced sugar content. Therefore, the change in sugar concentration could also be used to assess the banana's ripening process. However, the reduced sugar of coated fruits is lower than uncoated fruits. These findings show that the use of edible coatings on fruits lowers the reduced sugar values leading to extending the fruit's storage life (La *et al.*, 2021). These findings show that the use of edible coatings on bananas lowers the reduced sugar values leading to extending the banana fruit's storage life.

Coated banana goes through the reaction of hydrolysed starch into sugar becoming slow due to the reduction of respiration rate in bananas (Sarduni *et al.*, 2020). The results obtained thus proved that the effect of the pectin edible coating on fruit can delay the value of reducing sugar in the current study. Throughout the whole storage time, uncoated fruits showed a sharp rise in total sugar content compared to coated fruits, which showed a gradual increase (Himmam *et al.*, 2023). The shelf life of banana fruit was increased by using chitosan and Arabic gum edible coatings along with ZnONPs to significantly reduce the decreasing sugar levels (La *et al.*, 2021).

#### 4. Conclusion

In the present work, an edible coating with the combination of polysaccharide-based (alginate, carrageenan, and pectin) and ZnONPs for bananas was developed to examine the physicochemical changes that happened to the coated bananas. The physicochemical analysis shows the weight loss (significantly lower than uncoated), TA (significantly higher than uncoated), pH (significantly lower than uncoated), TSS (significantly lower than uncoated) reducing sugar (significantly increased than uncoated) and firmness (significantly higher than uncoated) of the coated bananas within a period. The application of coating on bananas resulted in notable alterations in their physicochemical attributes. These discoveries hold promising implications for post-harvest advancements, potentially enhancing farmers' earnings, and exports, and decreasing both food waste and its management. Exploring the implementation of this polysaccharide-derived coating on various food varieties could offer advantages to local agricultural producers.

#### Conflict of interest

The authors declare that they have no conflict of interest that could have appeared to influence the work reported in this paper.

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