BIOLOGY, MEDICINE, & NATURAL PRODUCT CHEMISTRY
Volume 14, Number 2, October 2025 | Pages: 927-935 | DOI: 10.14421/biomedich.2025.142.927-935
ISSN 2089-6514 (paper)
ISSN 2540-9328 (online)

Application of Alginate-Based Edible Coating with Beeswax Addition on Minimally Processed Pears (*Pyrus bretschneideri* Rehd.)

Maftukh Zaina Luthfiyyah, Novita Herdiana, Esa Ghanim Fadhallah*, Fibra Nurainy
Department of Agricultural Product Technology, Faculty of Agriculture, Universitas Lampung.
Jl. Prof. Dr. Soemantri Brojonegoro No. 1, Bandar Lampung, Lampung, 35145, Indonesia.

Corresponding author*
esa.ghanim@fp.unila.ac.id

Manuscript received: 16 July, 2025. Revision accepted: 27 October, 2025. Published: 28 October, 2025.

Abstract

Pears, especially after being cut, tended to experience a decline in quality and damage such as enzymatic browning, moisture loss, and texture changes. The application of alginate-based edible coating with the addition of beeswax was one of the innovations that could be applied to minimally processed pears to slow down the rate of deterioration. This study aimed to determine the effect of beeswax concentration in alginate-based edible coating solutions on the freshness of minimally processed pears and to identify the optimal beeswax concentration using the star method. The study was designed using a Completely Randomized Design (CRD) in a non-factorial arrangement with the addition of beeswax. The treatments consisted of six levels: BK as the control, B0 (alginate), B2 (alginate + 2% beeswax), B4 (alginate + 4% beeswax), B6 (alginate + 6% beeswax), and B8 (alginate + 8% beeswax), each with four replications. The results showed that the addition of beeswax to the alginate-based edible coating had a significant effect on moisture content, weight loss, firmness, total soluble solids, and color. The best treatment for maintaining pear freshness according to the star method was B4 (4% beeswax), which had a moisture content of 85.66%, weight loss of 1.79%, firmness of 874.63 gf, total soluble solids of 11.28 ˚Brix, and a lightness (L) value of 68.30 on day 12 of storage.

Keywords: Alginate; beeswax; edible coating.

INTRODUCTION

Horticultural products face a major challenge in their relatively short shelf life and perishable nature. One such horticultural product that is highly susceptible to damage is pear (*Pyrus bretschneideri* Rehd.) due to its high water content of approximately 84% (Widyaka et al., 2019). Pears are rich in nutrients, containing about 110 calories, 134 mg of potassium, and various vitamins (A, B1, B2, C, E, K, folacin, pantothenic acid, and niacin). According to Öztürk et al. (2014), the vitamin C content in pears ranges from 9.1 mg to 29.7 mg per 100 g of pear flesh. This abundance of nutrients makes pears popular among consumers worldwide. Based on data from USDA (2023), global pear production in 2023 is projected to reach 25.2 million tons, an increase of 300,000 tons from the previous year. In Indonesia, the consumption of pears is relatively high, as indicated by imports reaching 238,160 tons in 2020 (Badan Ketahanan Pangan, 2020).

Market trends such as fresh-cut fruits and vegetables are gaining popularity due to their convenience, ease of consumption, and fresh appearance. However, these products are highly perishable and typically last only 3–5 days due to respiration, transpiration, microbial activity, and insects (Hibatul, 2018). One innovation aimed at extending their shelf life is the application of edible coatings to the surface of the fruit. Edible coatings are thin layers that serve to enhance mechanical properties, provide antibacterial effects, and act as barriers to water vapor and gases (Galus and Kadzińska, 2015). According to Setiawan (2019), materials used for edible coatings should be resistant to oxygen and water vapor permeability, tasteless, colorless, and should not alter the characteristics of the food. Common materials used for edible coatings include tapioca starch and chitosan. However, these materials have several drawbacks, necessitating the use of other more effective substances such as alginate in preventing damage to pears.

Alginate has the ability to form films or biopolymer layers due to its unique colloidal structure and can be used as a suspending agent, thickener, film former, binder, and emulsifier. However, a limitation of alginate-based edible coatings is their poor mechanical properties, which can be improved by adding lipids. A study by Utomo and Salahudin (2015) showed that the addition of lipids to corn starch films increased their water resistance. One such lipid component is beeswax, which, due to its solid and hydrophobic structure, can restrict O_2 and CO_2 exchange and slow down oxidation and respiration (Baldwin et al., 2011).

This study utilizes alginate and beeswax as materials for producing edible coatings. Beeswax possesses hydrophobic properties that can inhibit moisture loss and reduce the rate of transpiration, thereby preventing excessive water evaporation (Oko et al., 2023). Based on the above explanation, it is necessary to conduct a study to determine the effect of alginate-based edible coatings with beeswax on the freshness of minimally processed pears.

MATERIALS AND METHODS

Raw material

Asian pear (Pyrus bretschneideri Rehd.) in fresh condition without major damage or defects was obtained from Pasar Tani, Bandar Lampung, with an average weight of approximately 300 g per fruit. Organic beeswax was sourced from a local honeybee farm in Tangerang Regency, Indonesia.

Experimental design

This study was arranged using a Completely Randomized Block Design (CRBD) in a non-factorial experiment with six treatment levels and four replications. The treatments consisted of control (BK), alginate only (B0), alginate + 2% beeswax (B2), alginate + 4% beeswax (B4), alginate + 6% beeswax (B6), and alginate + 8% beeswax (B8). The beeswax percentages were based on 100 mL of distilled water. Data obtained on days 6 and 12 of observation were analyzed for homogeneity of variance using Bartlett's test and for additivity using Tukey's test. The data were then subjected to analysis of variance (ANOVA) to estimate the error variance and evaluate the effect of treatments. Duncan's Multiple Range Test (DMRT) at the 5% significance level was performed to determine significant differences among treatments. The best treatment was selected using the star rating method.

Procedures

Preparation of Edible Coating Solution

Three a total of 100 mL of distilled water was heated to a temperature of 40°C, then 1.5 g of alginate was added and stirred for approximately 10 minutes. Next, 1% (1 mL) of glycerol was added as a plasticizer to improve the flexibility of the alginate layer. Subsequently, organic beeswax, obtained from local farmers in Tangerang Regency, and 0.1 mL of Tween 80 as an emulsifier were added to help incorporate ingredients that are typically immiscible, such as oil and water. The concentrations of beeswax and distilled water used were 2 g/100 mL, 4 g/100 mL, 6 g/100 mL, and 8 g/100 mL. The mixture was then heated at approximately 60–70°C while being stirred until homogeneous.

Application of Edible Coating

The application of the edible coating on the pears was based on a previous study by Chiabrando & Giovanna (2016), with modifications. Asian pears (*Pyrus bretschneideri* Rehd.) at 80% ripeness were selected and sorted based on color, size, and absence of pest damage. The pears were obtained from a farmer's market in Bandar Lampung, with an average fruit weight of approximately 300 g. The pears were washed with clean water and soaked in a 100 ppm chlorine solution for 5 minutes, then drained for 20 minutes. Chlorine compounds can inhibit enzymatic browning activity that causes discoloration of the fruit (Passafiume et al., 2021). The pears were then cut into crescent-shaped slices measuring 3 cm by 7 cm, with each piece weighing approximately 60–65 g.

Next, the samples were coated with the edible solution by immersing the entire fruit slices in the edible coating solution for 2 minutes and draining them for 1 minute. The pears were then immersed in 100 mL of 2% calcium chloride ($CaCl_2$) solution for 3 minutes to form cross-links in the alginate, thereby strengthening and stabilizing the coating layer. After that, the samples were air-dried at room temperature for 30 minutes and stored in a chiller (0–4°C) (Chiabrando & Giovanna, 2016). Observations were carried out on moisture content, weight loss, firmness, total soluble solids, color, and vitamin C content for the best treatment. The samples were analyzed periodically on days 0, 6, and 12.

Observation parameter

Moisture content

Moisture content was measured on days 0, 6, and 12 of observation. The measurement referred to the AOAC (Association of Official Analytical Collaboration, 2019) method, which involves evaporating water from the sample by heating in an oven at a specific temperature (typically 105°C) until a constant weight is achieved. The weight loss after heating is considered as the moisture content of the sample.

Weight Loss

Weight loss was determined by weighing the pears on days 0, 6, and 12 of observation. The initial weight (W0) was recorded before treatment, while the final weight (W1) was recorded after treatment. Thus, weight loss was calculated as the difference between the initial and final weights (Megasari and Mutia, 2019).

Fruit firmness

Fruit firmness was expressed in gram-force (gf) or Newton (N) and measured using a Brookfield CT3 texture analyzer. The pear was tested at three points (right end, left end, and center) using a 6 mm diameter probe, applied twice. The probe speed was set at 5 mm/s, and the sample was compressed to 30% of its original height. Firmness was measured on days 0, 6, and 12 of observation.

Total soluble solids

Total soluble solids (TSS) were measured on days 0, 6, and 12 of observation using a hand refractometer. Pear juice was obtained by grating the entire part of the fruit (one sample), and 1–2 drops of the juice were placed onto the refractometer sensor glass. The glass cover was then closed, and the °Brix value was read by aligning the blue line on the refractometer scale. The total soluble solids were expressed as a percentage (%) within a range of 0–32% (Arpani, 2019).

Color

Color parameters were measured using a colorimeter (AMT 507), with color values expressed in terms of L, a, and b* values. The colorimeter sensor was placed on the surface of the pear at three points: the right side, left side, and bottom. The measurement button was pressed to record the color data. Color parameters were measured on days 0, 6, and 12 of observation.

Vitamin C content

Vitamin C content was determined following the method described by Jacobs (1958). The samples used included the best treatment sample and the control sample. The first step involved grating the pear to obtain a homogenized sample. Then, 5–10 g of the homogenized or liquid sample was weighed and transferred into a 100 mL volumetric flask, followed by the addition of distilled water up to the calibration mark. The mixture was then filtered through filter paper or centrifuged to obtain the filtrate. An aliquot of 5–25 mL of the filtrate was pipetted into a 100 mL Erlenmeyer flask. Next, 2 mL of 1% starch solution was added as an indicator, and the mixture was titrated with 0.01 N standard iodine solution until a light blue color appeared.

RESULTS AND DISCUSSION

Moisture content

Based on the results, the moisture content of fresh-cut pears decreased during storage, with more pronounced effects as the storage period progressed. On day 0, all samples had an initial moisture content of 87.42%, representing the fresh condition of the pears prior to treatment and storage. On day 6, moisture content ranged between 84.55% and 86.87%, and further decreased to 83.63%–86.44% by day 12. According to Widyaka et al. (2019), the moisture content of fresh pears is approximately 84%. The observed reduction in moisture content indicates a decline in fruit quality, which affects weight, freshness, and shelf-life (Jannah, 2024). The decrease in moisture content in the B2 treatment (2% beeswax) on day 6 was only 0.63%, which is lower than that reported by Widyaka et al. (2019), who observed a 2.22% decrease in coated pear slices after 6 days of storage. This difference suggests that the combination of alginate and beeswax is effective in maintaining moisture in fresh-cut pears. The rate of moisture content in minimally processed pears are illustrated in Figure 1.

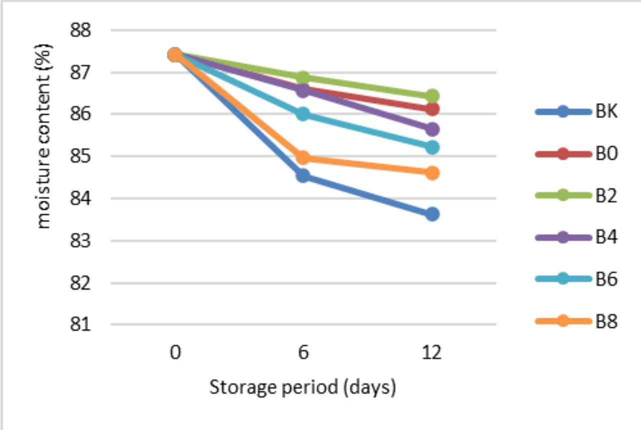

Figure 1. The rate of moisture loss in minimally processed pears under all treatments increased with storage duration.

Different beeswax concentrations in each treatment had varying effects on the moisture content. The control treatment without beeswax (BK) showed the lowest moisture levels, at 84.55% (day 6) and 83.63% (day 12). The absence of a protective coating allowed direct contact between the fruit surface and the environment, accelerating physiological processes such as respiration and transpiration, which in turn increased moisture loss and reduced fruit quality during storage (Mahfudin, 2016). Conversely, treatment B2 (2% beeswax) resulted in the highest moisture content, with 86.87% on day 6 and 86.44% on day 12, indicating that this concentration was the most effective in preserving fruit moisture. This finding suggests that moisture retention in fresh-cut pears is influenced by the concentration of beeswax used, with lower concentrations such as in B2 providing a more effective barrier to water vapor transmission. Treatments B4 and B6 also showed good effectiveness, although their moisture contents were slightly lower than that of B2.

Interestingly, treatment B8 (8% beeswax) resulted in lower moisture content (84.97% on day 6 and 84.62% on day 12) compared to treatments B2, B4, and B6. This suggests that higher beeswax concentrations do not necessarily enhance moisture retention. Excessive beeswax may form a coating layer that is too thick or uneven, potentially hindering gas exchange and inducing anaerobic respiration, which can accelerate fruit deterioration (Mahfudin, 2016). The effectiveness of the coating is also attributed to the combined use of alginate and beeswax. Alginate acts as a barrier to environmental factors, helping to retain moisture and reduce the risk of dehydration in the fruit (Jannah, 2024). According to Dhyan et al. (2015), waxing methods combined with low-temperature storage effectively slow down fruit metabolism, including respiration and transpiration, thus minimizing water loss. Maintaining moisture content plays an important role in increasing the fruit's resistance to damage caused by microorganisms and insects. Pathogenic microorganisms can more easily enter fruit tissues that have softened or sustained skin damage due to water loss (Dhyan et al., 2015).

Weight loss

Weight loss is defined as the difference between the initial and final weight of the fruit, where a higher percentage indicates a decline in the quality of fresh-cut pears (Mawardi et al., 2023). The results of this study show that the weight of fresh-cut pears decreased progressively during storage, with more pronounced effects observed over time. Weight loss during 6 days of storage ranged from 1.31% to 2.26%, and increased to 1.79%–3.40% by day 12. According to the DMRT test at a 5% significance level, treatment B4 was not significantly different from treatments B2 and B0 on both day 6 and day 12, but differed significantly from treatments B6, B8, and BK (control). All samples had 0% weight loss on day 0, indicating no initial degradation. These results indicate that the application of alginate-based edible coating with beeswax addition effectively maintained the quality of fresh-cut pears compared to uncoated fruit. The observed weight loss in this study was lower than that reported by Plesoianu & Nour (2022), who found that coated pear slices experienced a 4.20% weight loss after 12 days of storage. The rate of weight loss in minimally processed pears are illustrated in Figure 2.

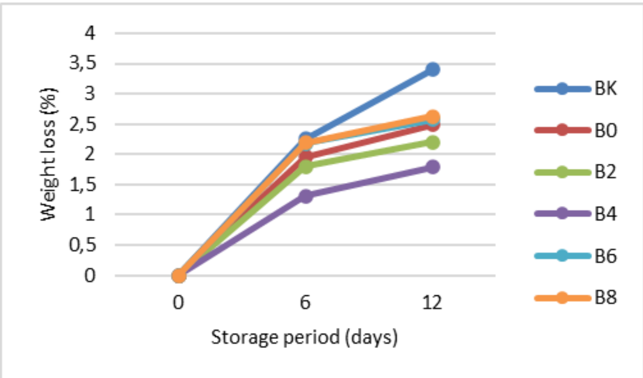

Figure 2. The rate of weight loss in minimally processed pears under all treatments increased with storage duration.

Treatments B2 (2% beeswax) and B4 (4% beeswax) consistently resulted in the lowest weight loss values on both day 6 and day 12. This can be attributed to the hydrophobic nature of beeswax, which reduces the size of surface pores on the fruit, thereby lowering water vapor transmission rates. Additionally, beeswax increases the barrier properties of the coating, contributing to a reduction in respiration rate (Kanani et al., 2018). However, excessive beeswax concentration, as seen in treatments B6 and B8, led to higher weight loss. According to Günal-Köroğlu & Çapanoğlu (2024), excessive wax may inhibit gas exchange and induce anaerobic respiration, whereas insufficient wax may fail to provide adequate protection. Effective wax coating can close stomatal openings, thereby reducing respiration rates (Mahfudin, 2016).

Weight loss in fresh-cut pears is closely related to water loss through transpiration and respiration processes. A high rate of water loss contributes to a decline in moisture content, which subsequently increases the percentage of weight loss. Plesoianu & Nour (2022) also explained that the primary cause of weight loss in fresh-cut fruit during storage is the evaporation of water through the exposed cut surface. Pear slices without coating (control) exhibited higher weight loss, which was also associated with lower moisture content. This is due to the absence of a protective layer that can slow down the rate of water evaporation. In contrast, edible coatings, particularly those containing beeswax, act as semi-permeable barriers that reduce transpiration and water vapor diffusion, thus maintaining moisture content and minimizing weight loss. This is supported by the results for both moisture content and weight loss in this study. On day 12 of storage, the control treatment (BK) showed the lowest moisture content (83.63%) (Figure 1) and the highest weight loss (3.40%) (Figure 2).

Fruit firmness

Based on the results presented in Figure 3, the firmness of minimally processed pears decreased over the storage period. On day 0, all samples had the same initial firmness value of 1108 gf, indicating that the physical condition of the fruit was uniform and had not yet undergone softening**.** The firmness of the pears on day 6 of storage ranged from 419.25 to 939.13 gf, and on day 12 ranged from 350.75 to 874.63 gf. The firmness continued to decline as the storage time increased. Treatment B4 (4% beeswax) showed a 15.25% decrease in firmness on day 6, which was higher than the findings of Widyaka et al. (2019), who reported that coated pear slices experienced a decrease in firmness of only 11.41–12.90%.

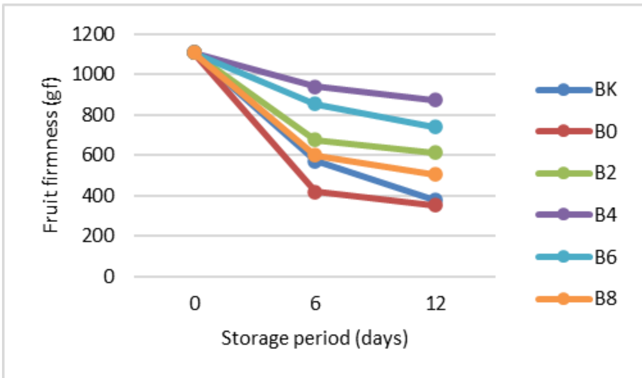

Figure 3. The rate of firmness reduction in minimally processed pears under all treatments increased with storage duration.

Variations in beeswax concentration produced differing effects on the firmness of fresh-cut pears.

Treatments B0 (without beeswax) and BK (control) exhibited the lowest firmness values during storage. This suggests that in the absence of a beeswax layer, the coating was less effective in preventing physical degradation, resulting in faster tissue softening. In contrast, treatments with added beeswax were more effective in maintaining fruit firmness. Treatment B6 (6% beeswax) demonstrated relatively good effectiveness, although slightly lower than B4, with firmness values of 854.38 gf on day 6 and 741.25 gf on day 12. Meanwhile, treatment B2 (2% beeswax) showed moderate firmness values, 675.38 gf (day 6) and 612.00 gf (day 12), indicating that while it provided some protection against softening, its effectiveness was still below that of B4 and B6. Interestingly, treatment B8 (8% beeswax), which utilized the highest concentration, resulted in lower firmness values, 599.75 gf (day 6) and 505.25 gf (day 12). These findings indicate that excessive beeswax concentration can lead to overly thick coatings, which excessively hinder gas exchange, induce anaerobic conditions within the fruit tissue, and accelerate the softening process (Susanto et al., 2018). Thus, beeswax concentrations that are too low are less effective in protecting the texture, while beeswax concentrations that are too high can cause side effects in the form of premature softening or fermentation triggered by limited oxygen in the fruit tissue due to the layer being too thick.

Fruit firmness or texture is closely associated with moisture content, as water loss leads to reduced cell turgor pressure, causing tissue softening. The decline in firmness observed in this study corresponds with the reduction in moisture content (Figure 1). Firmness in samples from BK (uncoated) and B0 (coating without beeswax) declined more rapidly due to higher rates of water loss. The effectiveness of beeswax in maintaining fruit firmness is attributed to its ability to form a barrier layer that reduces respiration rate and limits water evaporation, thereby preserving fruit texture.

According to Andriani et al. (2018), although softening is a natural consequence of storage, the incorporation of beeswax in the edible coating formulation has been shown to slow down this process. Genevois et al. (2016) reported that fruit softening is caused by the loss of cell turgor pressure due to the degradation of protopectin (insoluble pectin) into more than 40% soluble pectin. The application of beeswax in edible coatings may help delay this conversion by limiting gas and moisture exchange, thereby maintaining cell turgor and structural integrity. In addition to moisture loss through transpiration, the breakdown of complex compounds such as starch into simple sugars also contributes to accelerated softening of fruit texture (Atmaja, 2021). Therefore, edible coatings incorporating appropriate levels of beeswax can play an important role in preserving firmness and extending the shelf life of fresh-cut pears.

Total soluble solids

The results of the 5% DMRT test showed that treatment B8 was not significantly different from BK, B0, B2, and B6, but was significantly different from B4. The total soluble solids (TSS) of minimally processed pears increased during storage, from an initial value of 10 ˚Brix to 10.10–10.85 ˚Brix on day 6, and 9.98–11.28 ˚Brix on day 12 (Figure 4). TSS reflects the content of simple sugars such as glucose, fructose, and sucrose formed during the ripening process (Tabassum & Khan, 2020). Treatment B4 showed a consistent increase in TSS up to 11.35%. These findings are in line with Mohamed & Shaaban (2014), who reported an increase in TSS up to 11.59% in coated fresh-cut pears on the 12th day of storage. A higher TSS value indicates greater fruit sweetness (Mahadin, 2015). This is attributed to cell wall softening and the breakdown of complex carbohydrates into simple sugars, primarily through starch hydrolysis into sucrose, fructose, and glucose, which serve as key indicators of the fruit ripening process (Tabassum & Khan, 2020).

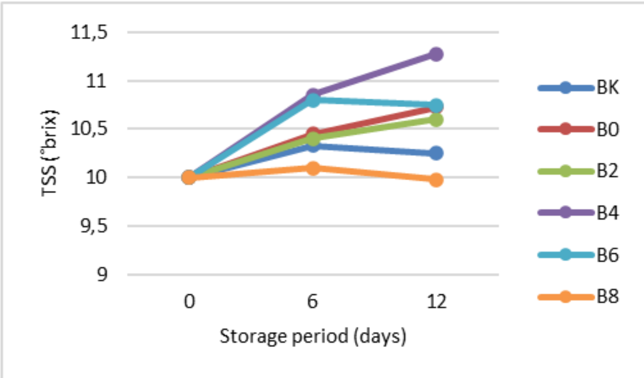

Figure 4. The rate of change in total soluble solids (TSS) of minimally processed pears in all treatments increased over the storage period.

Treatment B6 (6% beeswax) showed a relatively high increase in TSS, reaching 10.80°Brix on day 6 and 10.75°Brix on day 12, slightly lower than B4. Treatments B2 and B0 also exhibited increases in TSS, but with more moderate values. On day 12, treatment B2 reached 10.60°Brix, while B0 increased to 10.73°Brix. These increases indicate that ripening processes continued during storage, although the effectiveness of the coatings in controlling metabolic activity appeared lower in B2 and B0 compared to B4 and B6. In contrast, treatment B8 (8% beeswax) exhibited the lowest TSS values among all treatments, with 10.10°Brix on day 6 and 9.98°Brix on day 12. This suggests that excessively high concentrations of beeswax may restrict aerobic respiration due to the overly compact coating layer, which can interfere with metabolic processes and reduce sugar accumulation in the fruit (Susanto et al., 2018). The control treatment (BK) also showed lower TSS values compared to B2, B4, and B6, likely due to more rapid moisture loss in the absence of a protective coating, thereby affecting the internal balance of fruit metabolites.

Changes in TSS were also closely related to the observed variations in moisture content (Figure 1). As water evaporates, the concentration of dissolved substances such as sugars and organic acids increases, causing a rise in TSS values. Additionally, the increase in TSS reflects ongoing metabolic processes within the fruit, particularly the enzymatic breakdown of starch into simple sugars through hydrolysis, which is a key aspect of the ripening process. According to Refilda et al. (2022), increasing TSS levels are indicative of fruit ripening, and will continue to rise until the fruit reaches an overripe or spoiled state.

Color

Color change is a critical indicator in assessing the visual quality and consumer acceptability of fresh fruits during storage. Although coatings are often transparent and tend not to significantly alter the appearance of the fruit, color parameters are still commonly used as a subjective indicator of product quality (Suriati et al., 2022). In this study, the color of fresh-cut pears was measured using a colorimeter, and the color values were expressed in terms of lightness (L*), redness (a*), and yellowness (b*). Analysis of variance revealed that the addition of beeswax in the alginate-based edible coating had a significant effect on the color attributes of fresh-cut pears.

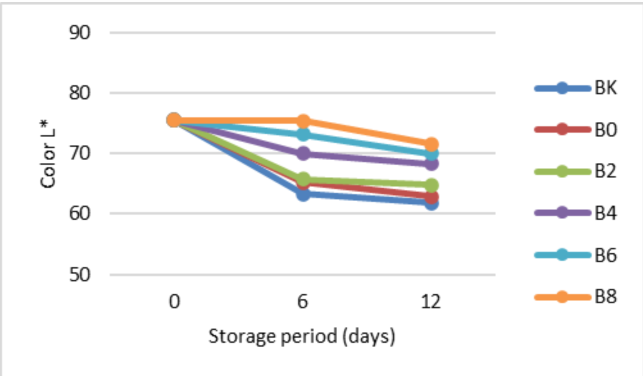

Figure 5. The rate of L color change in minimally processed pears under all treatments increased with storage duration

The a* value represents the green-red component of the sample color, where negative values (0 to –80) indicate greenness and positive values (0 to 80) indicate redness. The b* value measures the blue-yellow spectrum, with negative values (0 to –70) indicating blue and positive values (0 to 70) indicating yellow. According to Demasta et al. (2020), the a* and b* values are not strongly associated with polyphenol oxidase (PPO) activity, whereas the L* value (lightness) is significantly related to the inhibition of PPO activity. The L* value reflects the brightness of the sample, with 0 representing total darkness and 100 representing total brightness.At day 0, all samples exhibited an initial L* value of 75.50, indicating uniform brightness among fresh samples prior to treatment and storage. During storage, L* values on day 6 ranged from 63.33 to 75.40, while on day 12 they ranged from 61.90 to 71.55. Based on the 5% DMRT analysis, treatment B8 did not differ significantly from B6 and B4, but was significantly different from other treatments.

An increase in beeswax concentration was associated with higher L* values, indicating improved brightness. However, as storage time progressed, L* values declined across all treatments. For instance, the L* value for treatment B8 decreased by 5.23% by day 12, which aligns with findings by Plesoianu & Nour (2022), who reported a 4.6–7.7% decrease in L* values for coated pear slices during storage. This decline in lightness is commonly attributed to enzymatic and non-enzymatic browning reactions that occur following tissue damage caused by peeling and cutting (Kumar et al., 2018).

Higher beeswax concentrations in edible coatings effectively improved the L* index of fresh-cut pears during storage. A thicker coating layer created by higher beeswax levels helped limit oxygen penetration, thereby reducing browning. For example, treatment B8 (8% beeswax) maintained relatively high L* values throughout 12 days of storage, indicating that browning was effectively suppressed. Enzymatic browning in pears is initiated by polyphenol oxidase (PPO), which uses oxygen as a cofactor to convert phenolic compounds into o-quinones. These o-quinones undergo further polymerization, producing brown pigments and reducing surface brightness. Thus, limiting oxygen availability through beeswax coatings inhibits PPO activity and delays browning (Jannah, 2024).

Pears contain high levels of total phenolics—approximately 42.2–58.8 g GAE per kg dry matter in the peel and 6.4–17.7 g GAE per kg dry matter in the flesh (Piluzza et al., 2023). Although the peel, which contains higher phenolic content, was removed, the flesh still contains sufficient phenolics to trigger enzymatic browning. These phenolic compounds can rapidly oxidize if PPO activity is not inhibited or if oxygen is not restricted. In uncoated pears (control), the exposed surface facilitates rapid PPO activity and phenolic oxidation, resulting in a significant decline in L* values during storage (Purwanto et al., 2016).

Color changes in fresh-cut pears, particularly the decrease in L* values (lightness), are closely related to moisture loss during storage. Dehydration increases tissue exposure to oxygen, enhancing PPO activity. Uncoated pears (control) are more susceptible to browning due to greater water loss, which leaves the fruit surface more exposed to oxygen. Conversely, the application of edible coatings helps retain moisture and limit oxygen diffusion, thereby slowing down browning reactions. Moreover, fruit softening is often accompanied by more rapid browning, as cellular damage facilitates the interaction between phenolic compounds and PPO (Widyaka, 2018).

The combination of alginate and beeswax forms an effective protective barrier that limits oxygen diffusion to the fruit surface. Jannah (2024) reported that alginate can reduce respiration rates, thereby decreasing enzymatic reactions and maintaining surface color in apples. Alginate acts as a flexible film-forming agent, while beeswax enhances resistance to moisture and gas transfer due to its hydrophobic nature. This mechanism is crucial, as PPO is only active under aerobic conditions—thus, limiting oxygen availability reduces browning. Additionally, the coating acts as a barrier to water loss and prevents surface microstructural changes that can lead to dullness and drying of the fruit surface (Wulandari, 2016).

Vitamin C content

Pears contain antioxidant compounds such as vitamin C and vitamin E, which play an essential role in neutralizing free radicals. Vitamin C is especially important in supporting various metabolic processes in the human body, but it cannot be synthesized naturally and must be obtained through dietary intake. The main sources of vitamin C are vegetables and fruits, particularly those that are fresh, which is why it is often referred to as a "fresh food vitamin." According to Risnayanti et al. (2015), the vitamin C content is generally higher in unripe fruits and tends to decrease as the fruit ripens. In this study, the analysis of vitamin C content was carried out on the most effective treatment, which involved fresh-cut pears coated with an alginate-based edible coating containing 4% beeswax. The results of the vitamin C analysis for fresh-cut pears with edible coating are presented in Table 1.

Table 1. The vitamin C content of fresh-cut pears with edible coating was measured on day 12 of storage.

Treatment	Vitamin C content (mg/g)
BK (control, atau untreated)	0,0088
B4 (beeswax 4%)	0,0202

According to Koirala & Shrestha (2020), the vitamin C content in pears is approximately 12.2 mg/100 g. In this study, the vitamin C content of fresh-cut pears without edible coating (control) was recorded at 0.0088 mg/g, whereas the sample treated with 4% beeswax (B4) retained a higher vitamin C content of 0.0202 mg/g on day 12 of storage. This finding indicates that the application of beeswax-enhanced edible coating was more effective in preserving vitamin C levels compared to the control. The effectiveness is attributed to the formation of a thicker coating layer through the combination of alginate and beeswax, which reduced gas and water vapor permeability. As a result, respiration and transpiration rates were better controlled (Atmaja, 2021).

Vitamin C levels generally decline during storage due to oxidative processes, as ascorbic acid is highly sensitive to oxidation (Sunarmi et al., 2018). Atmaja (2021) explains that even under storage, respiratory and transpiration activities persist, allowing oxygen to penetrate the fruit tissue. In the presence of oxygen and the enzyme ascorbate oxidase, ascorbic acid is oxidized to dehydroascorbic acid, which then degrades into L-diketogulonic acid a compound that is no longer biologically active as vitamin C. High oxygen exposure accelerates the oxidation rate of vitamin C.

The use of edible coatings containing hydrophobic substances like beeswax can slow the degradation of vitamin C. Beeswax serves as a barrier that limits oxygen diffusion into the fruit tissue, thereby inhibiting oxidation. According to Linardi (2019), a higher concentration of hydrophobic materials in the coating can reduce the rate of vitamin C loss. Beeswax plays a critical role in restricting oxygen penetration from the environment into the pear tissue. A higher oxygen transfer rate increases respiration activity and water loss, during which vitamin C being water soluble may also diffuse out with the water (Atmaja, 2021).

CONCLUSIONS

The results of this study indicate that the addition of beeswax to alginate-based edible coating significantly affects the moisture content, weight loss, firmness, total soluble solids, and color of fresh-cut pears. The best physical and chemical characteristics are obtained from treatment B4 (4% beeswax) stored at chiller temperature (0–4°C) for 12 days, with a weight loss of 1.79%, firmness of 874.63 gf, total soluble solids of 11.28 °Brix, and vitamin C content of 0.0202 mg/g

Authors' Contributions: Maftukh Zaina Luthfiyyah, Novita Herdiana, Esa Ghanim Fadhallah, and Fibra Nurainy designed the study and wrote the manuscript in Bahasa. Maftukh Zaina Luthfiyyah conducted the research. Novita Herdiana, Esa Ghanim Fadhallah, and Fibra Nurainy supervised the research. Maftukh Zaina Luthfiyyah and Esa Ghanim Fadhallah translates to English and proofreads the manuscript. All authors read and approved the final version of the manuscript.

Competing Interests: The authors declare that there are no competing interests.

REFERENCES

Andriani, E. S., Nurwantoro, & Hintono, A. (2018). Perubahan fisik tomat selama penyimpanan pada suhu ruang akibat pelapisan dengan agar-agar. *Jurnal Teknologi Pangan*, 2(2), 176-182. doi: https://doi.org/10.14710/jtp.2018.20958

Arpani, N. A. P. (2019). Pengaruh Penstabil Tepung Ubi Jalar Terfermentasi Pada Pembuatan Yoghurt Pisang Ambon. *Skripsi*. Fakultas Pertanian, Universitas Lampung. Bandar Lampung.

Association of Analytical Chemists International (AOAC). (2019). *Official Methods of Analysis of AOAC Internasional 21st ed*. Chemist Incorporated. Washington D.C.

Atmaja, B. S. D. (2021). Optimasi Konsentrasi Tapioka, Lilin Lebah Madu, dan Gliserol Dalam *Edible Coating* untuk Meminimalkan Susut Bobot dan Penurunan Karakteristik Cabai Merah (*Capsicum annum* L.) yang Disimpan Selama 6 Hari Pada Suhu Ruang. *Skrispi*. Fakultas Pertanian, Universitas Lampung. Bandar Lampung.

Badan Ketahanan Pangan Kementrian Pertanian. (2020). *Analisis Ketersediaan Pangan Neraca Bahan Makanan Indonesia 2018 – 2020*. Pusat Ketersediaan dan Kerawanan Pangan. Jakarta.

Baldwin, E. A., Hagenmaier, R., & Bai, J. (2011). *Edible Coatings and Films to Improve Food Quality*. CRC Press. Boca Raton.

Chiabrando, V., & Giovanna, C. (2016). Effects of edible coatings on quality maintenance of fresh-cut nectarines. *Emirates Journal of Food and Agriculture*, 28(3), 201-207. doi: https://doi.org/10.9755/ejfa.2015-09-771

Demasta, E. K., Al-Baarri, N., & Legowo, A. M. (2018). Studi perubahan warna pada buah apel (*Malus domestica* B.) dengan perlakuan asam Hipoiodous (HIO). *Jurnal Teknologi Pangan*, 4(2), 145-148. doi: https://doi.org/10.14710/jtp.2020.20328

Dhyan, C. S., Sumarlan, S. H., & Susilo, B. (2015). Pengaruh pelapisan lilin lebah dan suhu penyimpanan terhadap kualitas buah jambu biji (*Psidium guajava* L.). *Jurnal Bioproses Komoditas Tropis*, 2(1), 79-90.

Galus, S., & Kadzińska, J. (2015). Food applications of emulsion-based edible films and coatings. *Trends in Food Science Technology*, 45(2), 273-283. doi: https://doi.org/10.1016/j.tifs.2015.07.011

Genevois, C. E., Pla, M. F. E., & Flores, S. K. (2016). Application of *edible coatings* to improve global quality of fortified pumpkin. *Innovative Food Science and Emerging Technologies*, 33(1), 506–514. doi: https://doi.org/10.1016/j.ifset.2015.11.001

Günal-Köroğlu, D., & Capanoglu, E. (2024). The effect of using natural plant-based waxes in coating/film materials on postharvest quality of fruits and vegetables. *Future Postharvest and Food*, 1(1), 166–172. doi: https://doi.org/10.1002/fpf2.12004

Hibatul, A. U. N. H. (2018). Perubahan Kualitas Buah Apel Manalagi Potong Dengan Pelapis *Edible* Berbasis CMC Dan Sari Lemon (*Citrus limon*). *Tesis*. Fakultas Teknologi Pertanian, Universitas Brawijaya. Malang.

Jacobs, M. B. (1958). *The Chemistry and Teknology of Food and Food Product*. Interscience Publisher. New York.

Jannah, F. R. (2024). Pengaruh Pelapis Sodium Alginat Dan Kalsium Klorida Dengan Perbedaan Jenis Agen Anti Browning Alami Terhadap Kualitas Apel (*Malus sylvestris* Mill.) Potong. *Skripsi*. Fakultas Sains dan Teknologi, Universitas Islam Negeri Maulana Malik Ibrahim. Malang.

Kanani, N., Ekasari, Wardalia, Subkhan, A., & Rizky, R. (2018). Pengaruh penambahan gliserol dan lilin lebah pada susut berat buah sawo khas banten. *Jurnal Ilmiah Terbuka Teknik Kimia*, 7(2), 37-44. doi: https://doi.org/10.24853/konversi.7.2.8

Koirala, B., & Shrestha, A. (2020). Comparative study of bioactive compounds in different varieties of pears in Nepal. *Nepal Journal Biotechnology*, 8(3), 95-101. doi: https://doi.org/10.3126/njb.v8i3.33663

Linardi, B. E. (2019). Pengaruh Konsentrasi Minyak Sawit dalam *Edible Coating* dan Lama Penyimpanan Pada Suhu Ruang Terhadap Sifat Fisik dan Kimia Jambu Biji Kristal. *Skripsi*. Fakultas Pertanian, Universitas Lampung. Bandar Lampung.

Mahadin. (2015). Aplikasi *Edible Coating* Berbasis Pati Singkong Untuk Memperpanjang Umur Simpan Buah Naga Terolah Minimal. *Skripsi*. Fakultas Teknologi Pertanian, Institut Pertanian Bogor. Bogor.

Mahfudin, Prabawa, S., & Sugianti, C. (2016). Kajian ekstrak daun randu (*Ceiba pentandra* L.) sebagai bahan *edible coating* terhadap sifat fisik dan kimia buah tomat selama penyimpanan. *Jurnal Industri Teknologi Pertanian*, 10(1), 16-23. doi: https://doi.org/10.24198/jt.vol10n1.3

Mawardi, R. F., Suhartatik, N., & Karyantina, M. (2023). The effectiveness of edible coating aloe vera (*Aloe vera chinensis* L.) in inhibiting enzymatic browning on sliced apples. *Jurnal Ilmiah Teknologi dan Industri Pangan UNISRI*, 8(2), 203-212. doi: https://doi.org/10.33061/jitipari.v8i2.7338

Megasari, R., & Mutia, A. K. (2019). Pengaruh lapisan *edible coating* kitosan pada cabai keriting (*Capsicum annum* L.) dengan penyimpanan suhu rendah. *Journal of Agritechnology Science*, 3(2), 118-127. doi: https://doi.org/10.30869/jasc.v3i2.389

Mohamed, A. Y. I., & Shaaban, F. K. M. (2014). Effect of some edible coating on quality of fresh pear slices during cold storage. *Middle East Journal of Applied Sciences*, 4(4), 1161-1170.

Oko, S., Kurniawan, A., Ramadhan, G., & Alam, P. (2023). Pengaruh penambahan massa lilin lebah (*beeswax*) sebagai zat anti air pada pembuatan *edible film* dari beras merah (*Oryza nivara*). *Jurnal Teknologi*, 15(1), 65-72. doi: https://doi.org/10.24853/jurtek.15.1.65-72

Öztürk, A., Demirsoy, L., Demirsoy, H., Asan, A., & Osman, G. (2014). Phenolic compounds and chemical characteristics of pears (*Pyrus Communis* L.). *International Journal of Food Properties*, 18(3), 536-546. doi: https://doi.org/10.1080/10942912.2013.835821

Passafiume, R., Gugliuzza, G., Gaglio, R., Busetta, G., Tinebra, I., Sortino, G., & Farina, V. (2021). Aloe-based edible coating to maintain quality of fresh-cut italian pears (*Pyrus communis* L.) during cold storage. *Horticulturae*, 7(12), 581-594. doi: https://doi.org/10.3390/horticulturae7120581

Plesoianu, A. M., & Nour, V. (2022). Pectin-based edible coating combined with chemical dips containing antimicrobials and antibrowning agents to maintain quality of fresh-cut pears. *Horticulturae*, 8(449), 1-18. doi: https://doi.org/10.3390/horticulturae8050449

Piluzza, G., Campesi, G., D'hallewin, G., Molinu, M. G., Re, G. A., Sanna, F., & Sulas, L. (2023). Antioxidants in fruit fractions of mediterranean ancient pear cultivars. *Molecules*, 2(8), 3559-3574. doi: https://doi.org/10.3390/molecules28083559

Purwanto, Y. A., & Effendi, R. N. (2016). Penggunaan asam askorbat dan lidah buaya untuk menghambat pencoklatan pada buah potong apel malang. *Jurnal Keteknikan Pertanian*, 4(2), 1-8. doi: https://doi.org/10.19028/jtep.04.2.203-210

Qotimah, K., Dewi, E. N., & Suharto, S. (2022). Pengaruh *edible coating* berbasis gelatin-alginat terhadap kemunduran mutu bakso ikan lele (*Clarias* sp.) pada penyimpanan suhu ruang. *Jurnal Ilmu dan Teknologi Perikanan*, 4(2), 93-99. doi: https://doi.org/10.14710/jitpi.2022.13508

Refilda, Ngestu, R. H., Salim, E., & Yefrida. (2022). Teknik *edible coating* dengan menggunakan campuran gel lidah buaya dan ekstrak daun *psidium guajava* l. untuk mempertahankan sifat fisikokimia buah jambu biji. *Jurnal Riset Kimia,* 13(2), 163-177. doi: https://doi.org/10.25077/jrk.v13i2.501

Risnayanti, Sabang, S. M., & Ratman. (2015). Analisis perbedaan kadar vitamin c buah naga merah (*Hylocereus polyrhizus*) dan buah naga putih (*Hylocereus undatus*) yang tumbuh di Desa Kolono kabupaten Morowali Provinsi Sulawesi Tengah. *Jurnal Akademika Kimia*, 4(2), 91-96.

Setiawan, M. A. (2019). Aplikasi Ekstrak Daun Cincau Hijau (*Cyclea barbata* L.M.) Sebagai *Edible Coating* Pada Mentimun (*Cucumis sativus* L.) Selama Masa Penyimpanan. *Skripsi*. Fakultas Pertanian, Universitas Lampung. Bandar Lampung.

Sunarmi, Maajid, L. A., & Kirwanto, A. (2018). Pengaruh lama penyimpanan terhadap kadar vitamin c buah apel (*Malus sylvestris* Mill.). *Jurnal Kebidanan dan Kesehatan Tradisional*, 3(2), 90-94. doi: https://doi.org/10.37341/jkkt.v3i2.88

Suriati, L., Utama, I. M. S., Harsojuwono, B. A., & Gunam, I. B. W. (2020). Incorporating additives for stability of Aloe gel potentially as an edible coating. *AIMS Agriculture and Food*, 5(3), 327–336. doi: https://doi.org/10.3934/agrfood.2020.3.327

Susanto, S., Inkorisa, D., & Hermansyah, D. (2018). Pelilinan efektif memperpanjang masa simpan buah jambu biji (*Psidium guajava* L.) 'kristal'. *Jurnal Hortikultura Indonesia*, 9(1), 19-26. doi: https://doi.org/10.29244/jhi.9.1.19-26

Tabassum, N., & Khan, M. A. (2020). Modified atmosphere packaging of fresh cut papaya using alginate based edible coating: Quality evaluation and shelf life study. *Scientia Horticulturae*, 259(1), 1-9. doi: https://doi.org/10.1016/j.scienta.2019.108853

United State Departement of Agriculture (USDA). (2023). *Fresh Apples, Grapes, and Pears: World Markets and Trade*. https://www.fas.usda.gov/data/fresh-apples-grapes-and-pears-world-markets-and-trade. Diakses Desember 2024.

Utomo, P. P., & Salahudin, F. (2015). Pengaruh inkorporasi lipid dan antioksidan terhadap sifat mekanik dan permeabilitas *edible film* pati jagung. *Biopropal Industri*, 6(1), 37-42.

Widyaka, V. H., Pranata, F. S., & Purwijatiningsih L. E. (2019). Application of starch *edible coating* which added asam kandis extract (*garcinia xanthochymus*) to pear fruit (*pyrus pyrifolia*) minimally process. *Journal Food Life Sciences*, 3(2), 82-91. doi: https://doi.org/10.21776/ub.jfls.2019.003.02.04

Widyaka, V. H. (2018). Aplikasi *Edible Coating* Pati Tapioka Dengan Penambahan Ekstrak Asam Kandis (*Garcinia xanthochymus*) Pada Buah Pir (*Pyrus pyrifolia*) Terolah Minimal. *Skripsi*. Fakultas Teknobiologi, Universitas Atma Jaya Yogyakarta. Yogyakarta.

Wulandari, C. (2016). Pengaruh Asam Sitrat Terhadap Indeks Browning, Kandungan Karbohidrat Terlarut Total, Dan Aktifitas Enzim Dehidrogenase Pada Buah Pir Yali (*Pyrus bretschneideri* Rehd.). *Skripsi*. Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Lampung. Bandar Lampung.