

Utilization of porang tuber starch enriched with ginger extract as an edible coating for avocado (*Persea americana* Mill.) storage

[Pemanfaatan pati umbi porang diperkaya ekstrak jahe sebagai edible coating untuk penyimpanan buah alpukat (*Persea americana* Mill.)]

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ABSTRACT

Avocado is a climacteric fruit that experiences a surge in respiration and ethylene production after harvest, which accelerates its deterioration. One method to extend its shelf life post-harvest is using edible coatings. This study evaluated the effects of various concentrations of edible coatings made from porang tuber starch and ginger extract on avocado quality during storage. A two-factor experiment was arranged in a randomized block design with 3 replications. The two factors studied were the concentrations of porang starch (0%, 1.5%, 2%, and 2.5%) and the concentrations of ginger extract (0%, 4%, 6%, and 8%). Observed parameters included weight loss, total soluble solids, firmness, damage percentage, and sensory color, texture, and taste evaluations. Storage was conducted at room temperature ($27\pm 2^{\circ}\text{C}$) for 10 days. The research results indicated that the quality of avocados was significantly affected by the single treatment using edible coatings made from porang starch or ginger extract, while the interaction between the two only had a significant effect on weight loss. The use of 2% porang starch or 6% ginger extract was able to reduce weight loss by up to 13.73%, maintain fruit firmness at $7.71\pm 1.383 \text{ kgf.cm}^{-2}$, total soluble solids at $1.25\pm 0.127^{\circ}\text{Brix}$, and resulted in sensory scores of color 1.67 ± 0.608 (purple), texture 1.58 ± 0.568 (soft), and taste 2.25 ± 0.688 (slightly liked). The damage rate of the avocados reached $47.21\pm 16.665\%$. Thus, this combination of edible coating proved effective in maintaining the physical, chemical, and sensory quality of avocados during storage.

Keywords: climacteric fruit, coating, ginger, storage, porang starch

ABSTRAK

Alpukat merupakan buah klimakterik yang mengalami lonjakan respirasi dan produksi etilen setelah dipanen, yang mempercepat kerusakan. Salah satu cara untuk memperpanjang umur simpan pascapanen adalah dengan menggunakan pelapisan yang dapat dimakan. Penelitian ini mengevaluasi efek berbagai konsentrasi pelapis edible berbahan dasar pati umbi porang dan ekstrak jahe terhadap kualitas alpukat selama penyimpanan. Penelitian ini menggunakan Rancangan Acak Kelompok (RAK) dengan dua faktor, yaitu konsentrasi pati porang (0%, 1,5%, 2%, dan 2,5%) dan konsentrasi ekstrak jahe sebesar (0%, 4%, 6%, dan 8%). Parameter yang dianalisis meliputi kehilangan bobot, total padatan terlarut, kekerasan, tingkat kerusakan, serta penilaian sensoris terhadap warna, tekstur, dan rasa. Penyimpanan dilakukan pada suhu ruang ($27\pm 2^{\circ}\text{C}$) selama 10 hari. Berdasarkan hasil penelitian, kualitas alpukat secara signifikan dipengaruhi oleh perlakuan tunggal menggunakan edible coating berbahan pati porang atau ekstrak jahe, sementara interaksi antara keduanya hanya memberikan pengaruh signifikan terhadap penurunan bobot. Penggunaan pati porang 2% atau ekstrak jahe 6%, mampu menekan kehilangan bobot hingga 13,73%, menjaga kekerasan buah pada $7,71\pm 1,383 \text{ kgf.cm}^{-2}$, total padatan terlarut sebesar $1,25\pm 0,127^{\circ}\text{Brix}$, serta menghasilkan skor sensoris warna $1,67\pm 0,608$ (ungu), tekstur $1,58\pm 0,568$ (lunak), dan rasa $2,25\pm 0,688$ (agak suka). Tingkat kerusakan alpukat mencapai $47,21\pm 16,665\%$. Berdasarkan hasil penelitian, edible coating kombinasi tersebut terbukti efektif menjaga kualitas alpukat selama penyimpanan berdasarkan hasil fisik, kimia, dan sensoris.

Kata kunci: buah klimakterik, jahe, pati porang, pelapisan, penyimpanan

Introduction

Avocado (*Persea americana* Mill) is a popular tropical fruit, widely consumed in regions such as Indonesia, which produced 854,331 tons in 2022, ranked as the fourth-largest avocado producer globally after Mexico, the Dominican Republic, and Peru (Badan Pusat Statistik, 2023). As a climacteric fruit, avocado continues to metabolize post-harvest, including respiration and transpiration, which shortens its shelf life and affects quality (Efendi et al., 2023). To address this, natural wax coatings can be applied to the fruit's skin, forming a thin layer that reduces respiration, prevents moisture loss, and regulates water transfer, thereby preserving color, nutrient content, and overall freshness. The coating often contains antimicrobials and antioxidants, which help improve the storage longevity of horticultural products (Tarihoran et al., 2023).

Edible coating is a thin, edible layer applied to fresh products to provide protection. This coating is made from materials such as hydrocolloids, lipids, or a combination of both (Janurianti et al., 2023). This technology shows significant potential in extending the shelf life of various food products, particularly fresh commodities, by serving several functions, including retaining moisture, regulating gas exchange, and inhibiting microbial growth (Nain et al., 2021; Nikhanj, 2023; Sapper & Chiralt, 2018).

The diversity of edible coatings is important, as they can be formulated from various ingredients such as starch, gum, and protein, which can be tailored to the needs of specific food products. Sago starch-based coatings have been shown to have good adhesion to fruits, improving storage quality (Yumeina, 2023). In addition, edible coatings can also be derived from porang tuber starch, which has been reported for its potential as a matrix for film formation (Fadhallah et al., 2023; Falah et al., 2021). The use of starch as a component in edible films is considered viable due to its excellent ability to block gases such as CO₂ and O₂, as well as its adequate resistance and adhesive strength. Furthermore, starch layers are odorless, tasteless, colorless, and safe for consumption (Pajak et al., 2013). The high glucomannan content in porang tubers makes them an effective thickening agent. Glucomannan can form a gel that is easily soluble in water, making it suitable for creating coatings that adhere to the surface of fruits (Amalia et al., 2020).

Porang (*Amorphophallus spp.*) is a plant in the taro family (Araceae) known for glucomannan-rich tubers, a hemicellulose polysaccharide composed of D-mannose and D-glucose, with a content of 15–65% in dry conditions. Glucomannan exhibits film formation, biocompatibility, biodegradability, and gelling ability, making it suitable for biopolymer and biodegradable polymer production (Falah et al., 2021). The glucomannan found in porang tubers, known as mannan, is a polymer composed of D-mannose and D-glucose. This compound has the ability to form an effective film layer and exhibits good biocompatibility (Faizin et al., 2023). Its hydrophilic nature makes glucomannan effective in limiting water evaporation, as seen in edible coatings.

Amalia et al. (2020) stated that coatings made from porang starch combined with galangal oleoresin reduced weight loss in bananas. Porang starch, with its long-chain glucomannan polysaccharides, provides strong adhesion for edible coatings, surpassing corn and rice starch. However, its hydrophilic nature makes these coatings prone to water damage, compromising their stability and mechanical properties.

Starch-only coatings are less effective than those enhanced with antioxidants or antimicrobial agents (Li et al., 2020; Sharifimehr et al., 2019). Adding antimicrobial agents like ginger extract to corn starch coatings can extend shelf life, reduce weight loss by 29.74%, and preserve texture, aroma, and flavor, as seen with cherry tomatoes (Ritonga et al., 2024). Further studies have shown that incorporating ginger root extract into starch-based coatings can enhance the quality and extend the shelf life of various fruits. Rangkuti et al. (2019) found that integrating 9% ginger rhizome extract into avocado seed starch formulations improved the fruit's storage life. Similarly, Efendi et al. (2023) revealed that a 6% ginger extract coating could maintain the soluble content of avocado fruit for up to 10 days of storage. This protective effect is primarily due to the natural antimicrobial properties of ginger extract, which inhibit microbial

growth and prevent spoilage, thereby extending the product's freshness (Li et al., 2020; Sharifimehr et al., 2019).

The combination of porang starch and ginger extract offers an innovative solution to extend avocado shelf life. Porang starch's adhesive and ginger's antimicrobial properties reduce spoilage, prevent water loss, and protect against microbial damage, helping maintain fruit quality during storage. This research highlights a promising approach to creating effective, eco-friendly coatings from natural materials. This research intended to examine the impact of different concentrations of edible coatings derived from porang tuber starch and ginger extract on enhancing the quality and extending the shelf life of avocados.

Materials and method

Materials and equipments

The materials utilized in this research included porang tubers, wholesome freshly harvested local variety avocados with green skin color and hard texture, fresh Emprit ginger, and Whattman paper no. 41. Chemicals used included distilled water and carboxymethyl cellulose (CMC).

Research design and data analysis

The research was carried out in several stages: extracting porang starch, preparing ginger extract, preparing edible coating, applying the coating to the avocado, storing the coated fruit, and conducting observations. The research was designed using a two-factor factorial pattern with a Randomized Group Design. The first factor is the edible coating made from porang tuber starch (P), with 4 treatment levels: 0% (P0), 1.5% (P1), 2% (P2), and 2.5% (P3). The second factor is ginger extract (J), with 4 treatment levels: 0% (J0), 4% (J1), 6% (J2), and 8% (J3). These two factors result in 16 experimental combinations. Each combination was repeated three times, resulting in 48 experimental units, each consisting of three fruit samples. The collected data were analyzed using ANOVA with 95% and 99% confidence levels. If the treatments had a significant effect, further analysis was conducted using the 5% LSD test.

Extraction of porang starch

Porang tubers were cleaned and sliced into 2 mm thick slices using a slicing machine (Lastrindo Engineering, Indonesia). The sliced were then soaked in salt water for 3 hours. The extraction process involved mixing the tubers with water at a weight-to-volume ratio of 1:4. The mixture was allowed to precipitate for 24 hours, followed by filtration to obtain the starch. This process (extraction, precipitation, and filtration) was repeated twice. The extracted starch was dehydrated in an electric oven (Memmert, Germany) at 55 °C for 14 hours. After dehydration, the starch was ground and sieved (100 mesh) to obtain dry starch.

Preparation of ginger extract

Ginger rhizomes, as much as 1000 g, were sorted and washed, then cut into small pieces and dried at 70 °C for 3 hours. The dried ginger was crushed into a pulp using a blender (Philips brand). Then, the ginger pulp was weighed at as much as 450 g, and 1000 ml of distilled water was added and allowed to stand for one night. The soaked ginger pulp was then filtered using Whattman filter paper no 41 to obtain the ginger extract.

Preparation of edible coating

Dry porang starch (as much as 1.5%, 2%, and 2.5%, each) was put into an Erlenmeyer containing distilled water, then heated on a hotplate stirrer at 80°C for 5 minutes until the suspension became clear or gelatinized. Then, the gelatinized porang starch was cooled to reach a temperature of 60°C. After that, the ginger extract at concentrations of 4%, 6%, and 8%, together with CMC and glycerol (1.65g each), were

added, stirred, and heated using a hotplate stirrer at 1000 rpm at 85°C for 30 minutes until evenly distributed. The temperature of the edible coating was then lowered to 40 °C so that it was ready to be applied to avocado fruit.

Edible coating application

The avocados were washed thoroughly and air-dried. They were then grouped by weight: Group 1 consisted of avocados with an average weight of 82–135 g, Group 2 had an average weight of 136–165 g, and Group 3 had an average weight of 167–264 g. The avocados were dipped into an edible layer made from porang starch mixed with ginger extract at approximately 40 °C for one minute, then were removed and air-dried. The avocados were arranged, both with and without the edible coating, on a tray and stored at room temperature (27±2°C) for 10 days in open containers.

Research parameters

Observation of avocado fruits was conducted over 10 days, assessing several parameters, including weight loss, fruit hardness, total soluble solids, damage level, percentage of damage, and sensory evaluation of texture, color, and taste, performed by 15 untrained panelists.

Weight loss

The weight loss was conducted following Efendi et al. (2023). It was calculated by comparing the fruit's weight on the first day of storage with its weight on the 10th day. A Precisa digital scale, model HGS, is used for the measurements. The percentage of weight loss is then determined using the following formula:

$$\text{Weight loss (\%)} = \frac{\text{initial weight (g)} - \text{final weight (g)}}{\text{initial weight (g)}} \times 100$$

Fruit hardness

The measurement of hardness was conducted following Manurung et al. (2024). It was measured using a GY-1 penetrometer equipped with a conical probe with a diameter of 8 mm. The test was conducted by poking the penetrometer needle into the surface of the avocado at a speed of 3 mm/sec and a pressure of approximately 9.8 N (1 kgf). Measurements were taken three times at different points: the tip, center, and base of the fruit. The obtained hardness value was recorded in kgf.cm⁻².

Sensory test

Sensory testing is a method of evaluation using human senses to assess product acceptance and plays a crucial role in quality assessment. In this study, sensory testing was conducted to evaluate the quality of avocado fruit during 10 days of storage, focusing on texture, color, and taste. Texture was assessed every two days (days 2, 4, 6, 8, and 10) using a 4-point Likert scale: 4 (hard), 3 (slightly hard), 2 (mushy), and 1 (very mushy) (Sundari et al., 2023). Color was also observed at the same intervals using a 4-point Likert scale: 4 (green), 3 (purplish green), 2 (purple), and 1 (brownish purple) (Aprilliani et al., 2021). Taste was evaluated only on the 10th day using a 4-point Likert scale: 4 (very like), 3 (like), 2 (dislike), and 1 (strongly dislike) (Lawless & Heymann, 2010).

Total dissolved solids

Total dissolved solids were measured using an ATAGO Refractometer described by Ayu et al. (2020). A portion of the avocado flesh was cut and collected, and a small amount of juice was dropped onto the refractometer prism. The sample was left to stabilize at 25 °C for one minute before measurement. After observing the difference between the light and dark areas, the refractive index value was read on the refractometer scale and expressed in °Brix units. Measurements were taken three times at different points: the base, center, and tip of the fruit.

Percentage damage

Observation of damage to avocados during storage was carried out by separating and classifying damaged avocados and those still suitable for consumption (Amalia et al., 2018). Damage criteria in avocados were observed visually based on moldy fruit skin, blackish-brown skin color at the base of the fruit, withering, and rot with a pungent odor. Observations were made on the 10th day of storage. The fruit damage was expressed as a percentage of damage using the formula as follows:

$$\text{Damage (\%)} = \frac{\text{number of damaged avocados}}{\text{number of avocados stored initially}} \times 100$$

Results and discussion

Weight loss

The ANOVA at $\alpha=0.05$ revealed an interaction between the application of edible coatings made from porang tuber starch and ginger extract on the weight loss of avocado fruit. The average weight loss over the 10-day storage period was between 13.73 to 29.42% (Table 1).

Table 1. Average weight loss of avocado fruit during 10 days of storage

Treatments	Weight loss (%)
Porang starch 0%, Ginger extracts 0%	29.42±2.907 ^a
Porang starch 0%, Ginger extracts 4%	22.70±3.369 ^b
Porang starch 0%, Ginger extracts 6%	21.66±2.417 ^{bc}
Porang starch 0%, Ginger extracts 8%	18.26±1.446 ^{defg}
Porang starch 1.5%, Ginger extracts 0%	19.98±1.675 ^{cd}
Porang starch 1.5%, Ginger extracts 4%	18.98±1.675 ^{de}
Porang starch 1.5%, Ginger extracts 6%	18.03±2.129 ^{defg}
Porang starch 1.5%, Ginger extracts 8%	16.56±3.520 ^{efg}
Porang starch 2.0%, Ginger extracts 0%	16.07±2.072 ^{fgh}
Porang starch 2.0%, Ginger extracts 4%	16.82±1.446 ^{efg}
Porang starch 2.0%, Ginger extracts 6%	13.73±0.680 ^h
Porang starch 2.0%, Ginger extracts 8%	16.22±2.744 ^{fgh}
Porang starch 2.5%, Ginger extracts 0%	16.92±1.135 ^{efg}
Porang starch 2.5%, Ginger extracts 4.0%	17.64±4.069 ^{defg}
Porang starch 2.5%, Ginger extracts 6.0%	15.67±3.377 ^{gh}
Porang starch 2.5%, Ginger extracts 8.0%	17.75±3.605 ^{defg}

Notes: Mean values accompanied by the same letter indicate no significant difference, as determined by the Least Significant Difference (LSD) test at a 0.05 significance level

Based on the LSD test ($\alpha = 0.05$) result, it was found that weight loss in avocados during 10 days of storage was effectively reduced through the application of an edible coating made from porang starch combined with ginger extract. The combination of 2.0% porang starch and 6% ginger extract was identified as the most effective treatment, resulting in a weight reduction of 13.73±0.680%. Generally, higher concentrations of edible coatings tend to lead to a more significant reduction in weight loss (Dwivany et al., 2020).

Weight reduction is referred to as the amount of fruit mass lost during storage, which is caused by respiration and transpiration processes. Glucose is broken down into CO₂ and H₂O through respiration, resulting in a loss of mass and energy (Anggarini et al., 2016). Mass reduction is a key indicator of fruit quality deterioration. The decline in avocado mass lost demonstrated that the use of a natural starch-based coating from porang tuber, combined with the right amount of ginger extract, can serve as a barrier to CO₂, O₂, and water vapor, effectively slowing the transpiration process. Hilma et al. (2018) noted that the increase in weight shrinkage was mainly due to high transpiration rates, where the fruit skin's opening and closing control the amount of water lost, consequently leading to greater weight loss. The use of a porang

tuber starch-based edible coating has been shown to effectively reduce avocado weight loss by creating a layer that slows down the transpiration process.

Edible coatings act as an extra protective layer on the surface of fruits, covering the stomata and reducing transpiration rates. Consequently, weight loss in fresh produce is minimized. This positive impact has been proven in a variety of produce, such as apples, papayas, carrots, guavas, plums, mangoes, apricots, bananas, oranges, mushrooms, and tomatoes (Salehi, 2020). The coating of fruit must be adjusted to the biological and structural characteristics of the fruit. A process of respiration without oxygen can be triggered by a coating layer that is too thick, accelerating fruit spoilage, while a layer that is too thin provides minimal protection, allowing excessive O₂ entry and increasing respiration (Tarihoran et al., 2023). Edible coatings are used in fruit preservation due to their ability to form a thin layer around the product. This layer serves as a physical barrier, influencing the exchange of gases and water vapor, which, in turn, alters the internal environment of the fruit and helps prevent moisture loss (Miranda et al., 2024).

Fruit hardness

The results of the ANOVA test at the $\alpha = 0.05$ significance level show that the edible coating formulated with porang tuber starch and ginger extract had a significant impact on the hardness of avocado fruit. However, the interaction between these two variables had no significant effect. The mean hardness values of avocado fruit during the 10-day storage period are shown in Tables 2 and 3.

Table 2. Average avocado fruit hardness on day 10 storage days (kgf.cm⁻²)

Porang Starch (%)	Fruit Hardness (kgf.cm ⁻²)
0	3.97±0.657 ^c
1.5	5.03±0.358 ^b
2.0	7.71±1.383 ^a
2.5	8.35±0.261 ^a

Notes: Numbers accompanied by different letters represent significant differences based on the LSD test at the 0.05 significance level

Table 3. Average avocado fruit hardness on day 10 storage days (kgf.cm⁻²)

Ginger extracts (%)	Fruit Hardness (kgf.cm ⁻²)
0	5.94±2.225 ^b
4	5.73±2.153 ^b
6	6.90±2.264 ^a
8	6.48± 2.091 ^{ab}

Notes: Numbers with the same letters indicate no significant differences based on the LSD test at the $\alpha 0.05$ level

During ripening, most starch is hydrolyzed into simple sugars, increasing sucrose, broken down into glucose and fructose. This process produces sweetness and reduces the firmness of ripe fruit. The results (Table 2) showed that the hardness of avocado fruit was 7.71±1.383kgf.cm⁻² and 8.35±0.261 kgf.cm⁻² when treated with an edible coating made from porang tuber starch at concentrations of 2% and 2.5%, respectively. As the concentration of porang starch increased, the fruit's hardness also improved. Edible coatings enhance firmness by inhibiting enzymes that damage the cell wall and slow down ripening (Das et al., 2013). The quality of avocado fruit is largely determined by its hardness, which is significantly influenced by the processes of respiration and transpiration. Applying a coating made from porang tuber starch reduces respiration and transpiration rates, helping to maintain the fruit's hardness and overall quality, allowing the fruit to maintain its hardness. Edible coatings are also effective in maintaining the texture and freshness of various vegetables, such as tomatoes, potatoes, carrots, spinach, and others (Méndez et al., 2020).

Shin et al. (2021) and Huang et al. (2022) explained that pectin, a key component in the cell wall, plays an important role in altering the texture during fruit ripening. In this process, protopectin, which is

insoluble in water, is converted into soluble pectin, leading to an increase in its solubility and a decrease in the cohesion of the cell wall. This change causes the fruit's texture to soften as its hardness decreases. The softening process occurs more rapidly when the fruit is stored at room temperature, as respiration accelerates the breakdown of compounds within the fruit, making the fruit structure even softer. Unlike other fruits that soften due to pectin breakdown, avocado texture changes are influenced by enzymatic degradation of hemicellulose and cellulose. Additionally, changes in oil content play a significant role (Anggarini et al., 2016).

The LSD test at α 0.05 (Table 3) showed that the highest avocado hardness values, $6.90 \pm 2.264 \text{ kgf.cm}^{-2}$ and $6.48 \pm 2.091 \text{ kgf.cm}^{-2}$, were found at ginger extract concentrations of 6% and 8%, respectively. In contrast, the lowest hardness was observed at a 4% ginger extract concentration, with an average value of $5.73 \pm 2.153 \text{ kgf.cm}^{-2}$. The concentration of ginger extract plays a key role in maintaining the hardness of avocado fruit, and increasing this concentration enhances its ability to preserve the fruit's firmness. Hardness is a key factor that reflects the quality and storage durability of avocado fruit. The processes of respiration and transpiration strongly influence fruit hardness. The decrease in avocado fruit hardness is inhibited by ginger extract. It was stated by Rangkuti et al. (2019) that the breakdown of pectin can be inhibited by increasing the concentration of ginger extract, allowing the hardness of the fruit to be maintained. With the addition of ginger extract, the edible coating can inhibit the degradation of complex compounds into simpler compounds, including protopectin. Protopectin is a pectate compound that gives fruit a hard texture. In avocados, protopectin is degraded into pectic acid and galacturonic acid, causing the texture of the avocado, which was initially hard, to change to soft.

Total dissolved solids

The results of the ANOVA test at a 5% significance level indicate that using edible coatings made from porang tuber starch and ginger extract separately significantly affected the total dissolved solids (TDS) of avocado fruit. However, the interaction between the two did not show a significant effect. The average total soluble solids can be seen in Tables 4 and 5.

Table 4. Average TDS of avocados at various concentrations of porang tuber starch ($^{\circ}\text{Brix}$)

Porang starch(%)	Total dissolved solids ($^{\circ}\text{Brix}$)
0	1.97 ± 0.138^a
1.5	1.55 ± 0.180^b
2.0	1.25 ± 0.127^c
2.5	1.18 ± 0.094^c

Notes: Numbers accompanied by different letters represent significant differences based on the LSD test at the 0.05 significance level

Table 5. The mean total dissolved solids of avocados at different concentrations of ginger extract ($^{\circ}\text{Brix}$)

Ginger extracts (%)	Total dissolved solids ($^{\circ}\text{Brix}$)
0	1.63 ± 0.352^a
4	1.53 ± 0.415^{ab}
6	1.39 ± 0.409^b
8	1.39 ± 0.278^b

Notes: Numbers accompanied by different letters represent significant differences based on the LSD test at the 0.05 significance level

Total dissolved solids indicate the sugar content in fruits, which influences their sweetness. The sweetness level of fruits fluctuates based on the quantity of dissolved solids. During storage, starches in fruits are converted into simpler sugars, increasing total dissolved solids (Feriani et al., 2023). Table 4 shows that without the use of porang starch-based edible coating, the total dissolved solids value is higher at $1.97 \pm 0.138^{\circ}\text{Brix}$ compared to those of treatments with edible coating, which show lower values for total dissolved solids. A decrease in total dissolved solids in avocados occurred as the concentration of the edible

coating increased, from 1.55 ± 0.180 °Brix at a concentration of 1.5% to 1.25 ± 0.127 °Brix at 2.0% and 1.18 ± 0.094 °Brix at 2.5%.

The edible coating functions as a protective layer that blocks gases like oxygen (O₂) and carbon dioxide (CO₂), along with other solutes, by creating a semipermeable membrane on the surface of the fruit. This slows down respiration, reduces water loss, and delays oxidation (Rusdianto et al., 2024). The reduced respiration inhibits sugar formation, keeping the sugar content stable and preserving the fruit's quality during storage. Total dissolved solids (TDS) indicate fruit ripeness, with higher values signaling increased respiration and transpiration. The Brix value also rises during fruit ripening as carbohydrates are converted into sugar. In rotting fruit, both TDS and Brix values continue to increase (Sari et al., 2024).

The use of ginger extract significantly affected the total soluble solids of avocados. Table 5 shows that the lowest total soluble solids were found in avocados treated with 6% ginger extract, with an average value of 1.39 ± 0.409 °Brix. Conversely, the highest total soluble solids was observed in the control treatment (0% ginger extract), with an average value of 1.63 °Brix. Thus, higher concentrations of ginger extract were correlated with lower total soluble solids in avocados.

The addition of ginger extract positively influenced avocados during 10 days of storage by forming a protective coating that limits oxygen intake, reducing aerobic respiration and ethylene production, thereby slowing ripening and extending shelf life. This aligns with the modified atmosphere storage theory, which emphasizes controlling gas permeability to maintain fruit quality (Kader, 2002). Ginger's bioactive compounds, such as gingerol and shogaol, also provide antimicrobial and antioxidant benefits, preserving texture, color, and taste (Laelago et al., 2023). Dahlan et al. (2024) highlighted that high respiration rates in ripe fruits increase total dissolved solids, while Rangkuti et al. (2019) observed that a 9% ginger extract coating decreased dissolved solids when compared to treatments without the coating.

Sensory test

The sensory evaluation of color, texture, and taste of avocados revealed that the edible coating made from porang starch and ginger extract had a notable impact, although the interaction between the two factors was not significant. This test involved 15 untrained panelists observing the avocados coated with the edible coating. The results of the 5% LSD test are presented in Tables 6 and 7.

Table 6. Sensory test scores for the color, texture, and taste of avocados coated with porang starch

Porang starch (%)	Color	Texture	Taste
0	1.00 ± 0.000^c	1.00 ± 0.000^b	1.00 ± 0.000^c
1.5	1.16 ± 0.000^{bc}	1.25 ± 0.165^{ab}	1.67 ± 0.274^b
2.0	1.67 ± 0.608^a	1.58 ± 0.568^a	2.25 ± 0.688^a
2.5	1.33 ± 0.387^b	1.25 ± 0.165^{ab}	2.33 ± 0.722^a

Description: Numbers followed by the same letters indicate no significant difference based on the LSD test at the 0.05 significance level. Color: scale 4 (green), 3 (purplish green), 2 (purple), 1 (Brownish purple). Texture: scale 4 (hard), 3 (slightly hard), 2 (mushy), and scale 1 (very mushy). Taste: scale 4 (very like), 3 (like), 2 (somewhat like), and 1 (dislike).

Table 6 shows that avocados coated with 2.0% porang starch received higher scores for skin color (1.67 ± 0.608), texture (1.58 ± 0.568), and flavor (2.25 ± 0.688) compared to the 1.5% concentration and without edible coating (0%), with significant differences. By the 10th day of observation, the avocado's skin had taken on a purplish-brown hue, and its texture had become soft, signifying that it was highly ripe. This color change was caused by decreased green chlorophyll pigment during the ripening process, where the chlorophyllase enzyme breaks down chlorophyll in climacteric fruit (Kalina & Navaratne, 2019). This ripening process causes the green pigment in the fruit's skin to change to yellow (as seen in bananas) and eventually brown due to the transformation of the pigment into o-quinone (Rachma et al., 2022).

The thin layer on the skin can prevent color deterioration during storage (Sembara et al., 2021). By coating the fruit, ethylene production can be slowed down, which ultimately helps delay the maturation processes, chlorophyll degradation, anthocyanin accumulation, and carotenoid formation (Shah & Hashmi, 2020). As ripening occurs, the color change corresponds with the storage duration. During this process, chlorophyll in the thylakoids breaks down, and lycopene accumulates in the chromoplasts (Jati et al., 2022). The slowing of green color degradation in fruits is attributed to the edible coating's ability to inhibit respiration, suppressing the activity of chlorophyllase, the enzyme responsible for breaking down chlorophyll. As stated by Wani et al. (2021), coatings can help reduce the activity of polyphenol oxidase and peroxidase enzymes, which are responsible for browning in both non-climacteric and climacteric fruits. This inhibition helps to slow or prevent the appearance of undesirable discoloration. Supporting this, Amalia et al. (2020) found that chlorophyll degradation contributes to color changes in avocados. The green color comes from chlorophyll pigments that change during storage through pheophytinization, chlorophyllide formation, and oxidation. Pheophytinization caused by acid produces pheophytin, which turns greenish-brown. Chlorophyllase enzymes break down chlorophyll into water-soluble chlorophyllide, while oxidation by oxygen and heat also alters its color (Kader, 2002).

Table 6 shows that avocados coated with 2.0% porang starch experienced softening, with a score of 1.58 ± 0.568 (very mushy), significantly different from avocados without coating. Porang starch has the ability to adhere and form a gel, which plays a role in maintaining the fruit's texture (Amalia et al., 2020). This coating has proven effective in extending the shelf life of the fruit by reducing water loss and protecting it from physical damage and microbial growth (Guerreiro et al., 2015). Avocados taste slightly bitter due to their tannin content (Humaira & Haryani, 2022). The sensory evaluation results shown in Table 6 indicate that avocados coated with 2.0% porang tuber starch received a taste acceptance score of 2.25 ± 0.688 (somewhat like), differing from avocados coated with 1.5% porang starch and those without coating (0%). The taste of avocados is strongly influenced by their ripeness level; unripe avocados tend to taste bitter, while overripe ones may taste bland or spoiled. The use of an edible coating made from porang tuber starch helps preserve the ripeness of avocados, thereby slowing down noticeable changes in taste. According to Nisah and Yanti (2019), an effective edible coating functions as a barrier to CO₂, O₂, and water vapor. This reduces transpiration, delays ripening, and preserves the fruit's taste for a longer period.

Table 7. Scoring of color, texture, and taste of avocado fruit stored for 10 days after ginger extract treatment

Ginger extract	Color	Texture	Taste
0	1.00±0.00 ^b	1.00±0.00 ^b	1.25±0.165 ^b
4	1.17±0.191 ^b	1.25±0.165 ^{ab}	1.92±0.739 ^a
6	1.67±0.543 ^a	1.50±0.576 ^a	2.17±0.999 ^a
8	1.58±0.419 ^a	1.33±0.274 ^{ab}	1.92±0.630 ^a

Note: Numbers with different letters (a, b) indicate statistically significant differences based on the LSD 0.05 test. Color: scale 4 (green), 3 (purplish green), 2 (purple), 1 (Brownish purple). Texture: scale 4 (hard), 3 (slightly hard), 2 (mushy), and scale 1 (very mushy). Taste: Scale 4 (very like), 3 (like), 2 (somewhat like), and 1 (dislike).

Table 7 shows that a 6% ginger extract concentration produced an avocado color close to purple, with a score of 1.67 ± 0.543 . This score was significantly different compared to the 4% and 0% ginger extract concentrations. Nisah & Yanti (2019) reported that antimicrobial compounds in ginger can slow down the discoloration process in fruits by inhibiting microorganisms responsible for spoilage. These microorganisms often play a major role in color changes and fruit damage. By reducing the number of microorganisms, ginger extract helps maintain the fruit's appearance, extend its shelf life, and minimize the risk of discoloration due to spoilage.

The addition of ginger extract also suppresses the fruit's softening process. Acting as an antimicrobial agent, red ginger extract enhances the effectiveness of edible coatings in preventing oxygen contact with fruit tissues. As a result, the activity of enzymes involved in respiration is inhibited. Ayu et al. (2020) stated

that antimicrobial components in edible coatings can reduce microbiological damage caused by microbial activity. These microbes convert carbohydrates into water-soluble substances, accelerating fruit tissue softening. This study is supported by Erviani et al. (2017), who stated that adding ginger filtrate at a 7% concentration to sago starch-based edible coatings can preserve the firmness of red chili peppers for up to 15 days. The taste of avocados is closely related to their ripeness. Unripe avocados tend to taste bitter, while overripe ones can taste bland or spoiled. The research results show that higher ginger extract concentrations decrease the taste rating of avocados. The fruit's flavor is influenced by the balance and intensity of non-volatile compounds, particularly sugars and acids.

Percentage of deterioration

The ANOVA results at $P < 0.05$ indicated that the use of coatings made from porang tuber starch and ginger extract had a significant effect on the percentage of damage to avocado fruit. However, their interaction did not have a significant effect. The percentage of avocado fruit damage up to the 10th day of storage can be seen in Table 8.

Table 8. The percentage of damage to avocados coated with porang starch edible coating during storage

Porang starch (%)	Damage (%)
0	100.00±0.000 ^a
1.5	52.77±13.980 ^b
2.0	47.21±16.665 ^b
2.5	58.32±10.639 ^b

Notes: Numbers followed by different letters (a, b, c) indicate significant differences in the LSD 0.05 test

Table 9. The percentage of damage to avocados treated with ginger extract during 10 days of storage

Ginger extracts (%)	Damage (%)
0	74.99±16.670 ^a
4	69.44±21.0384 ^{ab}
6	61.11±27.964 ^{bc}
8	52.77±31.919 ^c

Notes: Numbers followed by the letters a or b indicate significant differences at the 95% confidence level based on the LSD test.

The average percentage of avocado fruit damage on day 10 of storage is presented in Table 8. Avocados without an edible coating of porang tuber starch show a damage percentage of 100.00%, while those coated with 2.0% porang tuber starch exhibit a significantly lower damage rate of 47,21±16,665%. This highlights the effectiveness of the porang tuber starch edible coating in reducing fruit damage during storage. Sensory observations of the damage were based on the appearance of wrinkled skin, a pungent odor, mold growth, and blackish-brown discoloration at the fruit's base. The 2.0% concentration of porang starch was the most effective, likely because it allowed the fruit to continue normal respiration and transpiration. Nisah & Yanti (2019) explained that excessively high concentrations of edible coatings can hinder their effectiveness and lead to anaerobic respiration.

Table 9 also illustrates the effect of ginger extract on the percentage of damage to avocado fruit. The lowest damage percentage was observed in treatments with ginger extract concentrations of 6% and 8%, with average values of 61.11±27.964% and 52.77 ±31.919%, respectively. In contrast, the treatment without ginger extract showed a much higher damage percentage, averaging 74.99±16.670%. The results showed that as the concentration of ginger extract increases, the percentage of fruit damage decreases. Ginger extract acts as an antimicrobial agent that protects fruit coated with an edible layer from damage, while also extending shelf life and improving fruit quality, with higher concentrations reducing the level of damage (Rangkuti et al., 2019). Edible coatings have great potential as carriers of antimicrobial agents.

Incorporating antimicrobial compounds into the coating matrix can significantly reduce diseases and microbial loads on fruits (Passafiume et al., 2020; Shafiei & Mostaghim, 2022).

Conclusion

According to the research findings, the application of an edible coating with 2% porang tuber starch and 6% ginger extract did not reveal a significant interaction between the two components. However, both had a positive individual impact on the avocado fruit during 10 days of storage. The avocados treated with this coating demonstrated promising outcomes, as reflected in weight loss, fruit firmness, total soluble solids, and a damage rate of 47%. Sensory evaluations, including color, texture, and taste, also received favorable scores, suggesting the treatment's effectiveness in preserving the quality of avocados during storage.

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