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Preparation and characterization of carrageenan–based edible coating incorporated with lemon peel essential oil for quality improvement of strawberries

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Abstract

Strawberries (*Fragraria ananassa*) are fruit with high economic value because of their attractive colours, fresh taste, and good nutrition. However, it has a relatively short shelf life due to its higher water content and respiration rate than other fruit, making it easily damaged mechanically, physiologically, and microbiologically. One of the preservation methods is using edible coating, which has become quite popular in recent years because it effectively extends the post-harvest shelf life of fruit products. This research was conducted to determine the effect of different types of carrageenan (kappa and iota) and the concentration of lemon peel essential oil (0%, 0.3%, 0.5%, and 0.7%) on the quality of strawberries during refrigerated temperature storage. A completely randomized factorial design was employed, with the type of carrageenan and essential oil concentration as treatment factors. Results demonstrated that edible coatings based on carrageenan and lemon peel essential oil significantly influenced the quality parameters of strawberries, including total soluble solids (TSS), weight loss, moisture content, pH, vitamin C content, titratable acidity, total plate count, color, and texture. The selected formulation was kappa carrageenan combined with 0.7% lemon peel essential oil, which provided the best preservation effects by minimizing weight loss, maintaining firmness, and preserving the sensory quality of strawberries during storage.

Keywords: antimicrobial, polysaccharide, postharvest, refrigerated storage, shelf life

1. Introduction

Strawberries (*Fragaria ananassa*) are non-climacteric fruits that are popular because of their nutritional value and sensory properties [1]. Strawberries contain 35 kcal of energy, 41.2 mg of vitamin C, 4.56 g of sugar, 16 mg of calcium, and 148 mg of potassium [2]. Based on data from bulk payment system (BPS) BPS-Statistics Indonesia 2022-2023, the total strawberry production in Indonesia over the two years reached 56,616 tons [3]. Strawberries have a soft texture with a bright red to dark red colour, depending on the level of ripeness. While the strawberry ripens, its texture becomes smoother, increasing the possibility of physical damage during storage. Furthermore, strawberries have a high water content (approximately 90%), making them highly susceptible to microbial deterioration [2].

Strawberries' short shelf life poses a significant challenge for distribution and storage, with storage losses estimated at approximately 40% [4]. This damage can manifest as rot, changes in sensory characteristics, fungal and bacterial infections, or decreased nutritional value. To address these limitations, one promising approach is the application of edible coatings, which serve as a barrier to moisture, gases, and microbial invasion while maintaining the freshness of the fruit during storage and distribution.

Edible coating solutions have become one of the most popular methods for preserving food products. The use of edible coating materials offers several advantages: they are inexpensive, non-toxic, capable of controlling the migration of air-soluble components, inhibiting respiration and transpiration rates, preventing texture softening, and allowing selective gas permeability. Among the common elements of edible coating solutions are polysaccharides, such as starch and its derivatives, pectin, marine algae extracts (alginate, carrageenan, agar), xanthan, and chitosan [5]. Carrageenan is one of the primary materials for edible coating production due to its diverse, beneficial functional properties. There are three main types of commercially available carrageenan: kappa (κ), iota (ι), and lambda (λ), distinguished by the number and position of sulfate ester groups attached to their disaccharide units [6].

Kappa carrageenan, derived from *Kappaphycus alvarezii*, can form a strong, rigid gel with excellent gas barrier properties. In contrast, iota carrageenan, extracted from *Euchema denticulatum*, possesses good mechanical strength, high emulsion stability, and superior oxygen barrier performance [7]. Compared to other polysaccharides such as gum Arabic and xanthan gum, carrageenan has demonstrated exceptional performance when applied as an edible coating for fruits, particularly strawberries. Wani et al. [8] reported that carrageenan-based coatings were significantly more effective in reducing weight loss, maintaining fruit firmness, suppressing the activity of softening-related enzymes (such as polygalacturonase, cellulase, and pectin methylesterase), and preserving vitamin C content and antioxidant activity of strawberries during cold storage. Furthermore, carrageenan-based coatings resulted in a lower fruit decay rate and better retention of bioactive compounds compared to coatings made from Arabic gum and xanthan gum. Carrageenan is also effective when applied to other fruits, such as longan (*Dimocarpus longan*) coated with chitosan and sunflower extract, lasting 4 days [9].

Edible coating applications can be enriched with food additives such as anti-browning agents, antimicrobials, colourants, flavours, and nutraceuticals. One of the antimicrobial ingredients that can be used is essential oils, known as natural antioxidants and antibacterial solid agents because of their high concentration of phenolic compounds [10,11]. Lemon peels essential oils contain limonene, α-terpinene, α-pinene, β-pinene, coumarin, and polyphenols, which can be used as an antimicrobial in food coatings [12]. Among various citrus essential oils, lemon peel essential oil was selected in this study due to its superior antimicrobial efficacy. According to Rahmawati et al. [13], lemon peel essential oil exhibited the highest inhibitory activity against *Escherichia coli*, *Bacillus sp.*, *Rhizopus stolonifer*, and *Botrytis sp.*, compared to sweet orange and lime peel essential oils. The minimum inhibitory concentration (MIC) was 0.6% against bacteria and 1% against fungi, indicating its potent antimicrobial effectiveness at relatively low concentrations.

Based on the description above, edible coating from carrageenan with lemon peel essential oil can be applied to strawberries in storage and distribution. This study was conducted to determine the effect of the concentration of lemon peel essential oil included in carrageenan-based food coatings on the quality of strawberries in terms of physical properties (total dissolved solids, weight loss), chemical (water content, pH, vitamin C content, total titratable acid), microbiological (total plate count) and sensory (colour, hardness) during storage at refrigerated temperature (5±2°C). The application of edible coating using lemon peel essential oil is expected to increase the utilization of lemon peel waste, which can be used as an antimicrobial to maintain quality and extend the shelf life of food packaging.

2. Materials and methods

2.1 Materials

Materials used in this study were semi-refined kappa and iota carrageenan (PT. Galic Artabahari, Indonesia), lemon peel essential oil (CV. Eteris Nusantara, Indonesia), distilled water, and strawberries obtained from a local market (Pasar Gede Solo, Indonesia). Other reagents and buffer solutions, including amylum solution, iodine solution, phenolphthalein indicator, NaOH solution, plate count agar, and buffered peptone water, were purchased from PT. Brataco Chemical.

2.2 Preparation and Application of Edible Coating

Edible coating solutions were prepared following a previously reported method with some modifications [7]. First, 2 g of semi-refined kappa or iota carrageenan was dissolved in 98 mL of distilled water and stirred using a magnetic stirrer until the solution temperature reached 70°C for 10 minutes. Glycerol (1% w/w) was added to the solution, and stirring was continued while maintaining the temperature at 70°C for 10 minutes. After homogenization, the solution was cooled to 55°C for kappa carrageenan and 35°C for iota carrageenan. Lemon peel essential oil was prepared at concentrations of 0.3%, 0.5%, and 0.7% (v/v), and each concentration was mixed with an equal volume of Tween 80 (1:1 volume ratio) prior to incorporation into the coating solution. The mixture was stirred continuously until a homogeneous coating solution was obtained and ready for application.

Fresh strawberries of uniform size and color, free from visible damage, were selected to apply the edible coating. The fruits were washed under running water and allowed to drain until dry. The strawberries were then dipped into the coating solution for 5–10 seconds and allowed to drip for 5 minutes [14]. After ensuring no excess coating solution remained, the coated strawberries were dried in a food dehydrator at 45°C for approximately 15 minutes. The dried strawberries were individually packaged using transparent, hermetically sealed, thin-walled plastic containers. Paper towels were placed inside the packaging to absorb excess moisture. The packaged fruits were stored at refrigeration temperature (5 ± 2°C) until further analysis. Preliminary trials were also conducted using a higher concentration of lemon peel essential oil (1.0% v/v) following the same formulation procedure. However, at 1.0% concentration, the lemon aroma was excessively strong and adversely affected the sensory attributes of the strawberries. Therefore, only concentrations up to 0.7% were selected for further analysis to balance antimicrobial efficacy and sensory acceptability.

2.3 Physicochemical properties

Physicochemical analysis was carried out every 2 days for 6 days. The study carried out is the weight loss of the fruit, measured with an analytical balance based on comparing the initial weight (%) of the fruit before and after storage [9]. Moisture content was obtained using the thermogravimetric method. After putting 2 g of the sample into a cup of known weight, it was dried in an oven at 105°C for 3 hours. After that, it was cooled in a desiccator and weighed. Then, it dried for 30 minutes, cooled, and weighed repeatedly until a constant weight was reached [15].

Total Soluble Solids (TSS) testing using a hand refractometer by dripping crushed strawberry juice on the refractometer prism. The pH value of the strawberries was measured using a digital pH meter. The vitamin C content was determined using iodometric titration. A total of 10 g of strawberries was homogenized using a mortar, and distilled water was added to reach a final volume of 100 mL. The homogenate was filtered, and the resulting filtrate was titrated with a standardized iodine solution. The appearance of a persistent blue color indicated the endpoint of the titration. The total titratable acidity (TTA) was determined by acid-base titration. Similarly, 10 g of strawberries was homogenized using a mortar and diluted with distilled water to a final volume of 100 mL. After filtration, the strawberry juice was titrated with a standardized NaOH solution using phenolphthalein as an indicator. The appearance of a stable pink color marked the endpoint [16].

2.4 Total count of microorganisms

A total of 1 g of the sample was placed into a test tube containing 9 mL of sterile distilled water and homogenized. Serial dilutions were prepared by transferring 1 mL of the homogenate into 9 mL of sterile distilled water, continuing as necessary to reach the desired dilution (e.g., 10^{-1} to 10^{-3}). Subsequently, 1 mL of the appropriate dilution was aseptically transferred into a sterile Petri dish. Then, 15–20 mL of melted plate count agar (PCA) medium was poured into each dish, mixed gently, and allowed to solidify. The plates were incubated at 32°C for 24 hours, after which the number of colonies was counted using a digital colony counter [17].

2.5 Hedonic sensory analysis

Hedonic sensory analysis was carried out to determine the panelists' preferences for the texture and color of strawberries treated with edible coating during storage. 25 panelists were asked to rate the level of preference for strawberries on a scale: 1 = very dislike, 2 = dislike, 3 = neutral, 4 = like, 5 = really like. Panelists were asked to observe the overall color of the strawberry samples presented for color test parameters. Next, the panelists were asked to observe the texture of the strawberry sample that was served by pressing their fingers on the sample that had been served [18].

2.6 Statistical analysis

The experiment was arranged in a completely randomized factorial design with two factors: type of carrageenan (kappa and iota) and lemon peel essential oil concentrations (0%, 0.3%, 0.5%, and 0.7%), including a control. The control group in this study refers to strawberries that were not coated with carrageenan and essential oil. Observations were conducted on day 0, 2, 4, and 6 under refrigerated storage (5 ± 2 °C). Each treatment was performed in triplicate with duplicate analyses. Data were analyzed using the general linear model (GLM) Full Factorial. Significant differences were further evaluated using duncan's multiple range test (DMRT) for GLM and tukey's honestly significant difference (HSD) test for ANOVA at a significance level of $\alpha = 0.05$.

3. Result and discussion

3.1 Total Soluble Solid (TSS)

Polygalacturonase and pectin methyl esterase induce fruit softening through pectin degradation in the cell wall, which may subsequently influence the TSS content due to structural changes and the release of intracellular components[23]. Strawberries with kappa and iota carrageenan coating had an increase in total dissolved solids from day 0 until day 6. Uncoated strawberries have the highest increase in total dissolved solids until the end of storage time (Table 1).

Table 1 Effect of essential oil concentration on physicochemical characteristic strawberries during storage.

Parameters	EO Concentration (%)	Day 0	Day 2	Day 4	Day 6
TSS (%)	0	$6.43^{b} \pm 0.84$	6.89 ± 0.63	$7.21^{b} \pm 0.54$	$7.73^{c} \pm 0.64$
	0.3	$5.98^{ab} \pm 0.27$	$6.39^{ab} \pm 0.15$	$6.69^{b} \pm 0.44$	$7.08^{b} \pm 0.17$
	0.5	$5.89^{ab} \pm 0.35$	$6.25^{ab*} \pm 0.65$	$6.60^{ab} \pm 0.83$	$6.77^{b} \pm 0.90$
	0.7	$5.68^{a*} \pm 0.28$	$6.05^{a*} \pm 0.50$	$6.05^{a*} \pm 0.45$	$6.23^{a} \pm 0.12$
Weight loss (%)	0	0.00 ± 0.00	$1.44^{d} \pm 0.17$	$1.95^{d} \pm 0.59$	$3.57^{d} \pm 0.42$
	0.3	0.00 ± 0.00	$1.06^{c} \pm 0.04$	$1.25^{c} \pm 0.05$	$2.64^{c} \pm 0.14$
	0.5	0.00 ± 0.00	$0.86^{b} \pm 0.05$	$0.97^{b} \pm 0.06$	$1.88^{b} \pm 0.17$
	0.7	0.00 ± 0.00	$0.65^{a} \pm 0.10$	$0.78^{a} \pm 0.07$	$1.37^{a} \pm 0.15$
Moisture content (%)	0	$93.24^{a} \pm 0{,}69$	$92.51^{a} \pm 0.41$	$91.94^{ab} \pm 0.64$	$91.55^{a} \pm 0.92$
	0.3	$92.93^{a} \pm 0.72$	$92.69^{a} \pm 0.58$	$91.84^{ab} \pm 0.54$	$91.40^{a} \pm 0.90$
	0.5	$93.04^{b} \pm 0.73$	$92.64^{a} \pm 0.69$	$92.19^{b} \pm 0.76$	$91.56^{a} \pm 1.01$
	0.7	$92.64^{a} \pm 0.46$	$92.08^{a} \pm 0.23$	$91.42^{a} \pm 0.54$	$91.23^{a} \pm 0.59$
pH	0	$3.29^{a*} \pm 0.06$	$3.37^{b} \pm 0.05$	$3.45^{b} \pm 0.06$	$3.54^{b} \pm 0.04$
	0.3	$3.31^{a*} \pm 0.07$	$3.38^{b} \pm 0.05$	$3.44^{b} \pm 0.05$	$3.53^{b} \pm 0.03$
	0.5	$3.27^{a*} \pm 0.04$	$3.31^{a} \pm 0.05$	$3.37^{a} \pm 0.08$	$3.41^{a} \pm 0.06$
	0.7	$3.26^{a*} \pm 0.04$	$3.28^{a} \pm 0.03$	$3.33^{a} \pm 0.02$	$3.40^{a} \pm 0.08$
Vitamin C (mg/100g)	0	$61.99^{a} \pm 9.18$	$58.08^{a} \pm 5.70$	$56.32^{a} \pm 4.03$	$48.69^{a} \pm 3.84$
	0.3	$62.48^{a} \pm 3.82$	$56.32^{a} \pm 4.85$	$55.73^{a} \pm 4.12$	$52.21^{a} \pm 2.40$
	0.5	$66.88^{ab} \pm 6.86$	$63.65^{b} \pm 6.53$	$59.84^{ab} \pm 5.99$	$57.20^{b} \pm 5.42$
	0.7	$68.64^{b} \pm 2.95$	$65.71^{b} \pm 1.82$	$62.19^{b} \pm 3.08$	$60.43^{b} \pm 2.40$
TTA (%)	0	$0.22^{a} \pm 0.06$	$0.18^{a} \pm 0.03$	$0.16^{a} \pm 0.03$	$0.13^{a} \pm 0.03$
	0.3	$0.24^{ab} \pm 0.01$	$0.20^{a} \pm 0.01$	$0.18^{a} \pm 0.01$	$0.16^{b} \pm 0.01$
	0.5	$0.26^{c} \pm 0.03$	$0.23^{b} \pm 0.02$	$0.21^{b} \pm 0.02$	$0.18^{c} \pm 0.01$
	0.7	$0.32^{d} \pm 0.02$	$0.29^{c} \pm 0.02$	$0.26^{c} \pm 0.03$	$0.24^{d} \pm 0.02$

Results expressed as mean ± standard deviation.
Numbers followed by different superscript letters indicate significant differences at the ($p < 0{,}05$) in the same column.

An increase TSS in the fruit indicates an increase in the amount of dissolved materials such as glucose, sucrose, fructose, and minerals. The edible coating can form a layer that is good enough to protect the surface of the fruit so the respiratory process becomes obstructed. A low respiration rate can inhibit metabolic processes and chemical changes, so that the ripening process can be slowed and the shelf life becomes longer [21]. As shown in Table 1, the difference in lemon essential oil concentration causes a significant increase in TSS.

Strawberries treated with 0.7% essential oil exhibited significantly lower TSS values than the other concentrations (0%, 0.3%, and 0.5%) at the storage end. Strawberries with 0% essential oil concentration have the highest TSS until the end of storage. Essential oils can improve hydrophobicity properties in the edible coating layer to reduce the speed of respiration and metabolic processes in fruit. Retardation respiration in fruit can simultaneously inhibit the process of ripening that continues after the fruit is harvested. This causes sugar formation to be inhibited, and the TSS value will remain stable without increasing too high [16]. Combining carrageenan and essential oils in edible coatings has been demonstrated to delay ripening and reduce fruit decay while maintaining the TSS content [21]. The application of edible coatings enriched with essential oils has been shown to positively impact the materials' mechanical properties and water vapor barrier abilities, resulting in less weight loss and maintenance of TSS content in treated fruits [11].

3.2 Weight loss

Weight loss is the process of decreasing fruit weight as a result of processes of respiration, transpiration, and bacterial activity [15]. Strawberries still carry out the process of respiration and other metabolism after harvest. The metabolic process that occurs in fruit can be in the form of a breakdown of the contents stored in the fruit. These can result in an acceleration of the aging process and rotting of the fruit resulting in a shorter shelf life of the fruit.

The difference in lemon essential oil concentration causes a significant increase in weight loss. However, the strawberries control treatment had the highest weight loss at the end of storage at 3.57% (Table 1). Essential oils have been found to reduce weight loss in edible coatings due to their antimicrobial and barrier properties. When essential oils are incorporated into edible coatings, they can act as natural antimicrobial agents, inhibiting the growth of spoilage microorganisms and pathogens on the surface of fruits or food products [22]. Additionally, essential oils can improve the barrier qualities of edible coatings, which minimizes weight loss in fruits and food items and lowers water vapor transfer. The structural integrity of edible coatings can be strengthened by adding essential oils, which also form a barrier that prevents moisture from escaping the coated surface [23].

Strawberry coating with kappa and iota carrageenan had an increase in weight loss from day 0 to day 6 (Table 2). The processes of transpiration and respiration lead to increased weight loss. Because the coating provides a barrier and lets oxygen into the strawberry, strawberries without an edible coating lose weight significantly. There is a possibility of increased respiration, leading to increased water loss. The production of edible coating containing kappa carrageenan is more effective in reducing strawberry weight. An iota produces a thinner edible coating than a kappa. Strawberries containing kappa carrageenan lost 2.18% of their weight on the final day of storage, whereas Iota lost up to 2.45% (Table 2). When it comes to gel formers, Kappa is preferable to Iota. The permeability of gas and water vapor is also influenced by coating thickness. This is because the edible coating's permeability to gas and water vapor decreases with thickness [24].

Table 2 Effect of carrageenan type on physicochemical characteristic strawberries during storage.

Parameters	Type of carrageenan	Day 0	Day 2	Day 4	Day 6
TSS (^{0}brix)	Control	$6.97^{b*} \pm 0.55$	$7.35^{b*} \pm 0.33$	$7.87^{b} \pm 0.23$	$8.47^{b} \pm 0.30$
	Kappa	$5.91^{a*} \pm 0.44$	$6.28^{a*} \pm 0.71$	$6.49^{a} \pm 0.70$	$6.73^{a} \pm 0.70$
	Iota	$5.94^{a*} \pm 0.57$	$6.62^{a*} \pm 0.57$	$6.62^{a} \pm 0.48$	$6.99^{a} \pm 0.56$
Weight loss (%)	Control	0.00 ± 0.00	$1.66^{c} \pm 0.03$	$2.72^{c} \pm 0.14$	$3.98^{c} \pm 0.48$
	Kappa	0.00 ± 0.00	$0.93^{a} \pm 0.28$	$1.08^{a} \pm 0.29$	$2.18^{a} \pm 0.80$
	Iota	0.00 ± 0.00	$1.025^{b} \pm 0.25$	$1.20^{b} \pm 0.32$	$2.45^{b} \pm 0.79$
Moisture content (%)	Control	$93.96^{b} \pm 0.75$	$92.43^{a} \pm 0,79$	$92.20^{a} \pm 0.95$	$91.31^{a} \pm 1.07$
	Kappa	$93.06^{a} \pm 0.66$	$92.65^{a} \pm 0,60$	$92.09^{a} \pm 0.65$	$91.72^{a} \pm 0.93$
	Iota	$92.69^{a} \pm 0.39$	$92.33^{a} \pm 0,34$	$91.53^{a} \pm 0.44$	$91.21^{a} \pm 0.66$
pH	Control	$3.29^{a*} \pm 0.04$	$3.37^{a*} \pm 0.06$	$3.42^{a*} \pm 0.09$	$3.53^{b*} \pm 0.06$
	Kappa	$3.31^{a*} \pm 0.05$	$3.35^{ab*} \pm 0.06$	$3.41^{a*} \pm 0.08$	$3.45^{a*} \pm 0.09$
	Iota	$3.26^{a*} \pm 0.04$	$3.31^{b*} \pm 0.06$	$3.39^{a*} \pm 0.06$	$3.49^{ab*} \pm 0.08$
Vitamin C (mg/100g)	Control	$72.16^{b} \pm 4.66$	$63.95^{b} \pm 5.38$	$58.67^{a*} \pm 2.03$	$46.93^{a*} \pm 2.03$
	Kappa	$61.31^{a} \pm 7.15$	$58.52^{a} \pm 6.37$	$57.35^{a*} \pm 4.89$	$54.12^{b*} \pm 4.38$
	Iota	$66.15^{a} \pm 5.28$	$61.89^{ab} \pm 5.85$	$59.11^{a*} \pm 5.49$	$55.59^{b*} \pm 6.77$
TTA (%)	Control	$0.27^{a} \pm 0.08$	$0.20^{a*} \pm 0.03$	$0.16^{a*} \pm 0.03$	$0.12^{a} \pm 0.01$
	Kappa	$0.25^{a} \pm 0.05$	$0.23^{b*} \pm 0.05$	$0.21^{b*} \pm 0.04$	$0.19^{b} \pm 0.04$
	Iota	$0.26^{a} \pm 0.05$	$0.22^{ab*} \pm 0.05$	$0.20^{b*} \pm 0.05$	$0.17^{b} \pm 0.05$

Results expressed as mean ± standard deviation.
Numbers followed by different superscript letters indicate significant differences at the ($p < 0,05$) in the same column.

3.3 *Moisture Content*

The moisture content in fruit during storage is crucial for determining its quality and shelf life. Studies have shown that the moisture content of fruits can change during storage, impacting various physicochemical properties and quality attributes. The decrease in moisture content during storage can affect the texture, appearance, and overall acceptability of fruits, making it essential to maintain optimal moisture levels to ensure product quality and consumer satisfaction. The application of lemon essential oil at various concentrations did not affect the water content of strawberries. Strawberry water content decreased from day 0 to day 6 (Table 1). Strawberries without essential oils have the highest reduction in water content up to final storage. The most minor reduction in moisture content was observed in strawberries coated with kappa-carrageenan, with a decrease of only 1.34%, from 93.06% on Day 0 to 91.72% on Day 6. Essential oil with 0.7% can increase hydrophobic properties on the coating layer, reducing hydrophilic properties and acting as a barrier against water vapour [25].

Edible coating with kappa and iota carrageenan did not significantly affect the water content of strawberries during storage (Table 2). Strawberry water content decreased from day 0 to day 6. Uncoated strawberries have the highest decrease in water content until the end of storage. The application of coatings, such as carrageenan and essential oil coatings, has been reported to help maintain the moisture content of fruits during storage. These coatings act as barriers to moisture and oxygen, preserving the internal atmosphere of the fruit and reducing moisture loss. By maintaining the moisture content, these coatings can contribute to extending the shelf life of fruits and preserving their quality attributes [26].

3.4 *pH value*

The natural pH of strawberries typically ranges from 3.0 to 3.9, which makes them an acidic fruit. The acidity of strawberries contributes to their characteristic tartness and flavour profile. The low pH of strawberries is due to organic acids, such as citric acid and malic acid, which naturally occur in the fruit. The difference in lemon essential oil concentration causes an increase in pH value from day 0 to day 6 (Table 1). Strawberry coating without essential oil had the highest increase in pH value until the end of storage. Based on research results, strawberries with the addition of 0.5% and 0.7% essential oils had significantly lower pH values than the other two concentrations (0% and 0.3%). Applying coating with essential oils can significantly reduce fruit respiration levels. This effect is attributed to essential oils' antioxidant activity and gas barrier properties, which form a coating on the fruit surface. This coating can modify the internal gas composition by limiting oxygen entry and carbon dioxide release, thereby reducing the respiration rate of the fruit. A suppressed respiration rate can reduce metabolic activity in the form of changes in organic acids and the fruit’s acidity level and pH value can be maintained. They can extend the shelf life of the fruit [4,15].

Differences in treatment with variations in the type of carrageenan had no significant effect ($p>0.05$) on the strawberry coating from day 0 to day 6. Strawberries have an increase in pH value from day 0 to day 6. Uncoated strawberries have an increased pH value until the end of storage (Table 2). The longer the fruit storage period, the total acid in the fruit decreases because it is used as energy in the respiration process, which converts organic acids into sugar and decreases the total acid with storage time [27]. The decline in strawberry pH during storage can be mitigated by applying edible coatings containing kappa- or iota-carrageenan, which help reduce the fruit's respiration rate. [28].

3.5 *Vitamin C*

The difference in lemon essential oil concentration causes a decrease in vitamin C content (Table 1). The vitamin C content of coating strawberries with the concentration of essential oils at 0% decreased significantly compared to the others. Strawberries with adding 0.5% and 0.7% essential oils had significantly lower reduction values than both concentrations (0% and 0.3%). The incorporation of essential oils in edible coatings has been shown to inhibit the breakdown of Vitamin C due to the activity of antioxidant phenolics in the essential oils. These antioxidant compounds help to stabilize Vitamin C and prevent its degradation during storage, thereby maintaining the nutritional quality of the fruit [29].

The lemon essential oil contains 57.463% limonene, 4.142% beta-Myrcene, 11.979% gamma-Terpinene, and 10.917% 2-(2-Methylphenyl) thiirane [12]. This compound is a monoterpene hydrocarbon component capable of producing antioxidant activity because it has conjugated double bonds and can transfer hydrogen, reducing or inhibiting free radicals [30]. In a previous study, strawberries treated with edible coating Arabic gum, carrageenan, xanthan gum, and 1% lemongrass essential oil had 0.5-0.27 g/kg of retained ascorbic acid [14].

Strawberries with edible coating iota and kappa carrageenan showed decreased vitamin C during 6 days of storage at refrigeration temperature. Uncoated strawberries had the highest decrease in vitamin C value until the end of storage (Table 2). Treatment with edible coating is considered more effective than the control (without edible coating). Previous research by Gupta et.al [31] observed the effect of natural deep eutectic solvent

(NADES) starch-based coating on strawberries. Their study and using NADES as a coating solution was able to maintain the vitamin C content in strawberries for as long as storage compared to samples without edible coating. Coating with starch NADES on the surface of strawberries is considered capable of inhibiting oxidation reactions, and there is degradation of ascorbic acid to 2-keto-L-gluconate. Edible coating can inhibit the presence of vitamin C breakdown, which can also be slowed. On control strawberries not coated with an edible coating, the O_2 diffusion process cannot occur inhibited, resulting in continued degradation of vitamin C content in strawberries [31].

3.6 Total Titratable Acidity (TTA)

Total titrated acid is a better predictor of the effect of acidity on taste and aroma than pH. The total titrated acid value includes measurements of total dissociated and undissociated acids. The difference in lemon essential oil concentration causes decreased TTA (Table 1). Strawberries with the addition of 0.7% lemon essential oil have a value significantly lower than the three concentrations (0%, 0.3%, 0.5%). Edible coatings containing essential oils can help maintain total acidity in fruits by creating a protective barrier that reduces exposure to factors contributing to acidity breakdown. Essential oils, known for their antimicrobial and antioxidant properties, can help stabilize the acidity levels in fruits by inhibiting enzymatic reactions that lead to acid degradation [32]. Incorporating essential oils in edible coatings can shield against external factors that may accelerate the breakdown of acids, thereby preserving the total acidity in fruits during storage [21].

The different types of carrageenan caused strawberries to decrease total titratable acids from day 0 until day 6 (Table 2). Strawberries without edible coating had the highest decrease in total titratable acid until the end of storage. Strawberries generally had a reduction in total acidity titrated during the fruit ripening process. The reduction in total acidity during the fruit ripening process can be attributed to various factors, including changes in metabolic processes, gene expression, and hormone regulation [33]. Yin et al. [34] studied the effects of chitosan- and alginate-based coatings enriched with cinnamon essential oil microcapsules on mangoes. The coated mangoes showed inhibited decreases in titratable acidity content compared to uncoated mangoes. This is likely due to the coating’s ability to reduce respiration rate and limit oxygen permeability, slowing the metabolic consumption of organic acids during storage.

3.7 Hedonic sensory color and texture

Colour attributes are essential in attractiveness, identification marks, and quality attributes. Color is one of the critical parameters that can describe the quality of strawberries. Changes in strawberry color during the storage period can be seen in Figures 1 and 2. Treatment of differences in kappa and iota carrageenan types and essential oil concentrations had a significant effect ($p < 0.05$) on panellists' preferences for strawberry colour attributes (Table 5). On day 0, the panellists' liking level value for the strawberry color attribute was between 2.30 and 3.60 (dislike–neutral).

Meanwhile, on day 6, panelists’ favourite level values for the strawberry colour attribute ranged from 2.4 to 4.03 (dislike – like). An increase in panelists' level of favorability attribute of strawberry colour is thought to be because the colour of strawberries changes over time. The colour of the strawberries will become redder and darker. During the ripening process and storage, there is a synthesis of certain pigments, such as carotenoids and flavonoids, in addition to the breakdown of chlorophyll, which causes changes in the colour of strawberries [2].

Figure 1 Change in color of strawberries during storage using kappa carrageenan.

Table 3 Panelists level of preference for color attributes of strawberry.

Samples	Score			
	Color Day 0	Color Day 6	Texture Day 0	Texture Day 6
Control	$2.30^{a} \pm 1.15$	$2.43^{a} \pm 1.17$	$2.77^{a} \pm 1.30$	$2.83^{a} \pm 1.39$
Kappa carrageenan & 0% EO	$2.70^{ab} \pm 0.95$	$3.53^{bcd} \pm 1.36$	$3.37^{a} \pm 1.22$	$3.70^{ab} \pm 0.99$
Kappa carrageenan & 0.3% EO	$2.50^{a} \pm 1.04$	$2.53^{a} \pm 1.11$	$3.30^{a} \pm 0.84$	$3.47^{ab} \pm 1.01$
Kappa carrageenan & 0.5% EO	$2.60^{a} \pm 1.04$	$2.77^{abc} \pm 1.04$	$3.50^{a} \pm 1.04$	$3.80^{ab} \pm 1.00$
Kappa carrageenan & 0.7% EO	$2.93^{abc} \pm 1.08$	$2.70^{ab} \pm 1.12$	$3.47^{a} \pm 1.04$	$3.53^{ab} \pm 1.07$
Iota carrageenan & 0% EO	$2.93^{abc} \pm 1.08$	$3.87^{d} \pm 1.04$	$3.00^{a} \pm 1.11$	$3.10^{ab} \pm 1.30$
Iota carrageenan & 0.3% EO	$3.50^{bc} \pm 1.01$	$3.70^{d} \pm 1.24$	$2.90^{a} \pm 0.96$	$2.93^{ab} \pm 1.36$
Iota carrageenan & 0.5% EO	$3.60^{d} \pm 0.93$	$4.03^{d} \pm 1.00$	$2.83^{a} \pm 1.12$	$3.10^{b} \pm 1.06$
Iota carrageenan & 0.7% EO	$3.57^{d} \pm 1.30$	$3.63^{cd} \pm 1.13$	$2.93^{ab} \pm 0.94$	$3.00^{ab} \pm 1.17$

Results expressed as mean ± standard deviation.
Numbers followed by different superscript letters indicate significant differences at the 0,05-significance level in the same column.
The symbol * indicates the result of the analysis of significance level $p > 0.05$ in the same columns.

Textural attributes are one of the most important sensory parameters for determining the quality of food products. Texture can also be used as an indicator of fruit damage. Differences in treatment with variations in carrageenan type and essential oil concentration had significant effects (p <0.05) on texture preferences on days 0 and 6 (Table 3). On day 0, the value of panelists' level of preference for strawberry texture attributes ranged from 2.77 to 3.50 (dislike–neutral). Meanwhile, day 6 ranged from 2.83 – 3.80 (dislike – neutral). The low level of panelists' preference for the texture of strawberries during storage is thought to be due to this could be caused by a decreased texture quality of strawberries with edible coating during the storage period.

Changes in the physicochemical properties of strawberries during storage, such as an increase in TSS, pH, total sugar, and reducing sugar, coupled with a decrease in titratable acidity (TA) and ascorbic acid content, can contribute to alterations in texture. The decrease in firmness observed during storage, along with a reduction in colour saturation, can also impact the overall texture properties of strawberries.

Figure 2 Change in color of strawberries during storage using Iota carrageenan.

Edible coatings are known to play a crucial role in maintaining and enhancing the colour of strawberries during storage. Previous research by Velickova et al. [28] has demonstrated that the use of chitosan-beeswax coatings on strawberries improves visual appearance and taste, making them more preferred by panellists. Similarly, studies have indicated that polysaccharide-based edible coatings enriched with essential oils do not affect the colour of strawberries, suggesting their potential to maintain the original colour of the fruit [35].

3.8 Total Count of Microorganisms (TPC)

TPC is the quantitative method used to determine the count of all microbial colonies contained in fruit, including bacteria, mold, and yeast, by growing them on agar media. TPC results for strawberries without edible coating were 5.29 log CFU/g on day 4 and 6.23 log CFU/g on day 6. Meanwhile, strawberries with edible coating kappa were 4.98 log CFU/g on day 4 and 5.61 log CFU/g on day 6 (Table 4). The edible coating on the fruit reduces moisture loss and limits gas exchange, thereby creating less favorable conditions for the growth of aerobic microorganisms. This may be attributed to the type of carrageenan used, with kappa-carrageenan showing a more pronounced effect than iota-carrageenan. This structure is marked by combining or cross-linking polymer chains to form a continuous three-dimensional mesh. This mesh collects and immobilizes the air, creating a strong and rigid structure [6]. Carrageenan coatings have been shown to have antimicrobial properties that can help inhibit the growth of microorganisms responsible for spoilage and decay in strawberry fruits [36].

Table 4 Effect of carrageenan type on total plate count analysis results of strawberry.

Type of Carrageenan	Total Plate Count (Log CFU/g)			
	Day 0	Day 2	Day 4	Day 6
Control	$4.22^{c} \pm 0,01$	$4.94^{c} \pm 0.01$	$5.29^{c} \pm 0.00$	$6.23^{c} \pm 0.01$
Kappa	$3.97^{a} \pm 0,10$	$4.68^{a} \pm 0.16$	$4.98^{a} \pm 0.14$	$5.61^{a} \pm 0.18$
Iota	$4.02^{b} \pm 0,10$	$4.78^{b} \pm 0.09$	$5.16^{b} \pm 0.07$	$5.68^{b} \pm 0.19$

Results expressed as mean ± standard deviation.
Numbers followed by different superscript letters indicate significant differences at the 0,05-significance level in the same column.
The symbol * indicates the result of the analysis of significance level $p > 0.05$ in the same columns.

Coated strawberries without adding essential oils had the highest increase in total plate count value until the end of storage. Coating strawberries with the addition of 0.7% essential oil has a value that was significantly lower than the other three concentrations (0%, 0.3%, 0.5%) (Table 5). The slowing of microbial growth is due to active substances in essential oils that can inhibit microbial growth on the fruit surface. Lemon essential oil contains limonene as a volatile compound [12]. Several studies have demonstrated that limonene in citrus essential oil has an antimicrobial effect against a variety of microorganisms. The antimicrobial activity of limonene is attributed to its ability to disrupt the cell membranes of microorganisms, leading to cell leakage and inhibition of essential cellular processes [30,37].

Table 5 Effect of essential oil concentration on total plate count analysis results of strawberry.

Essential Oil Concentration	Total Plate Count (Log CFU/g)			
	Day 0	Day 2	Day 4	Day 6
0%	$4.14^{d} \pm 0.06$	$4.89^{d} \pm 0.05$	$5.21^{d} \pm 0.10$	$6.02^{d} \pm 0.16$
0,3%	$4.06^{c} \pm 0.02$	$4.77^{c} \pm 0.03$	$5.13^{c} \pm 0.06$	$5.67^{c} \pm 0.09$
0,5%	$3.94^{b} \pm 0.06$	$4.72^{b} \pm 0.02$	$5.07^{b} \pm 0.07$	$5.53^{b} \pm 0.06$
0,7%	$3.87^{a} \pm 0.01$	$4.56^{a} \pm 0.15$	$4.90^{a} \pm 0.18$	$5.44^{a} \pm 0.04$

Results expressed as mean ± standard deviation.
Numbers followed by different superscript letters indicate significant differences at the 0,05-significance level in the same column.
The symbol * indicates the result of the analysis of significance level $p > 0.05$ in the same columns.

4. Conclusions

Applying edible coatings composed of carrageenan and lemon peel essential oil enhanced the shelf life and overall quality of strawberries during storage. Due to its stronger and more rigid polymer structure, Kappa-carrageenan was more effective than iota-carrageenan in reducing moisture loss and limiting gas exchange. These barrier properties help slow respiration, reduce oxidative degradation, and inhibit microbial growth, preserving key quality parameters. Furthermore, the incorporation of lemon essential oil enhanced the coating's functionality, with the 0.7% concentration being the most effective in maintaining TSS, minimizing weight loss, and preserving vitamin C content.

5. Conflict of interest

The authors declare no competing interest.

6. References

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