

Performance of Maltodextrin-pectin-based Edible Coating with Lemongrass Essential Oil for Extending the Shelf Life of Fresh Tomatoes

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ABSTRACT

Tomatoes are highly perishable fruits that continue metabolic and respiratory activities after harvest, leading to nutrient degradation and rapid spoilage. Edible coatings offer an environmentally friendly solution owing to their biodegradability and low environmental impact. This study examined the effect of incorporating lemongrass essential oil (EO) into a maltodextrin-pectin-based protective coating on tomato quality and shelf life. The protective coating was applied by spraying after 20 days at temperatures between 30 °C and 4 °C. Both coated and uncoated samples (control) were analysed based on parameters such as colour change, hardness, mass loss, bacterial growth, and physical damage. The concentrations of lemongrass essential oil used were 0%, 0.5%, 1%, 1.5%, and 2% (v/v). The results showed that a concentration of 2% was the most effective in enhancing the function of

the protective coating, which was characterised by reduced weight loss, better texture retention, and inhibited microbial activity. After 20 days of storage, the fruit exhibited weight loss of 0.05% at 30 °C and 0.04% at 4 °C. In addition, the colour change was relatively small, and the tomato flavour remained stable. Thus, the use of a natural protective coating based on lemongrass essential oil can reduce post-harvest losses in perishable fruit.

Keywords: Edible film, essential oil, post-harvest, tomato

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INTRODUCTION

Tomatoes (*Solanum lycopersicum L.*) are cultivated worldwide and contain various vitamins and phytochemicals that are extremely beneficial for human health. Nevertheless, due to their climacteric nature, tomatoes face various issues throughout the post-harvest period since they ripen even after harvesting. It is caused by several physical, physiological, and pathological factors that greatly influence tomato physiology (Ozer et al., 2022). In addition, postharvest technologies such as edible coatings and modified atmosphere packaging play an important role in maintaining quality and extending shelf life by reducing moisture loss and regulating gas exchange (Garcia et al., 2014; Murugan et al., 2022; Perez-Vazquez et al., 2023). Such an interrelation of factors negatively affects the shelf life and commercial potential of the fruit (Colombié et al., 2017). Moreover, ethylene is one of the hormones that regulate ripening and is synthesised by 1-aminocyclopropane-1-carboxylic acid synthase (ACS) and 1-aminocyclopropane-1-carboxylic acid oxidase (ACO) genes. Thus, extensive knowledge of the mechanisms of ethylene-based tomato ripening is of paramount importance for increasing the shelf life of tomatoes (Pontiggia et al., 2019).

To maintain the quality of the fruits throughout their transport and storage period, post-harvest processing is required. The physiological activities leading to fruit ageing, such as respiration, senescence, and ripening, can be regulated using post-harvest processing. The application of edible films, which is an effective method for enhancing the quality and shelf-life of fresh fruits, has received substantial attention in recent years. Normally used as a thin film, edible films create a barrier that inhibits the deterioration process involving activities such as respiration, oxidation, and dehydration (Duan et al., 2019). Edible protective films are an effective and sustainable way to preserve fruits and vegetables. There are three major components in edible films, including hydrocolloids (proteins and polysaccharides), lipids (fatty acids), and composites/hydrocolloids-lipid blends (Liyanapathirane et al., 2023). The use of this film effectively reduced oxidation reactions, slowed respiration, and suppressed physiological disorders in horticultural products (Garcia et al., 2014). Avramescu et al. (2020) stated that edible protective films generally consist of high-quality food ingredients, thus maintaining the nutritional quality and sensory characteristics of fresh produce. Meanwhile, Ruan et al. (2019) explained that polysaccharide-based films have excellent barrier properties due to the presence of tightly arranged hydrogen bonds within their structure.

Selecting an appropriate coating substrate is another crucial factor. In view of the findings presented by Khezerlou et al. (2023) and Aswini et al. (2022), the inclusion of diverse biopolymer blends, including protein-based, polysaccharide-based, and lipid-based biopolymers, might be useful in improving the performance of the films and consequently minimising the losses of moisture, gases, and oxidative reactions within the produce. The types of base biopolymers that can be used for coating have been identified by

Pacheco et al. (2021) and include pullulan, maltodextrin, starch, hydrolysed collagen, gelatin, alginate, chitosan, and pectin.

The study conducted by Siswanto et al. (2023) investigated the use of maltodextrin as a film-forming material for stabilising lemongrass oil emulsions. Their findings demonstrated that maltodextrin significantly improved the quality and stability of the film, attributed to its capacity to produce a strong yet flexible film structure. This makes it an effective coating agent because it helps reduce water losses and decrease respiration rates (Perez-Vázquez et al., 2023). Nevertheless, the application of maltodextrin as a film-forming agent in thin edible films is limited. As a natural polysaccharide, pectin contributes to the film-forming ability of the coating and enhances moisture retention, thereby preserving the freshness and texture of produce.

According to Rohasmizah and Azizah (2022), pectin is ideal for producing edible films and coatings because of its superior gelling, thickening, and stabilising characteristics. Additionally, coatings made from pectin can prolong the shelf life of fruits by as much as 11 days by slowing down changes in weight loss, total soluble solids, pH, total acidity, firmness, and colour (Menezes & Athmaselvi, 2016). Simultaneously, another study assessed the use of coatings made from pectin-maltodextrin and sodium chloride on starfruit. This involved a 1% solution of pectin-maltodextrin in a 60:40 ratio, which demonstrated promise in preserving fruit quality during storage (Mohd Suhaimi et al., 2021). Several studies have individually analysed the effects of pectin and maltodextrin in creating edible films from fruits. Together, these two ingredients have proven useful in developing edible films that can entrap and retain bioactive molecules and increase film durability (Nazari Kermanshahi et al., 2021; Slimani et al., 2025). Further investigations should be conducted to determine their optimal concentrations and processing parameters.

Natural antimicrobials and antioxidants, such as essential oils, have attracted significant research interest for their application in improving the functional attributes of edible films. Films embedded with essential oils (EOs) have proven their ability to lower microbial populations in food (Lakshan et al., 2024; Yousuf et al., 2021). In the current study, lemongrass EOs (*Cymbopogon nardus*) were incorporated into edible coatings as antimicrobial agents. The composition of lemongrass EOs includes limonene, geraniol, and citronellol, which are known for their antibacterial activity and capability to retard bacterial proliferation (Trinetta et al., 2017). Lemongrass EOs are widely known for their antibacterial, antifungal, and antiviral properties, making them effective against a wide range of pathogenic microorganisms. Active compounds, phenols, and aldehydes, inhibit microbial activity by destabilising the lipid layer and disrupting bacterial cell membranes. Furthermore, lemongrass essential oil also plays a role in preventing the formation of bacterial biofilms (Mukarram et al., 2022). Several recent investigations found that the use of lemongrass essential oils (EOs) nanoemulsions incorporated within chitosan coatings

leads to an increase in the storage period for bananas (Putra et al., 2025). It has also been found that a mixture coating, which includes xanthan gum with lemongrass EOs, can be helpful in reducing oxidative stress in Kinnow mandarin fruits, thereby improving their nutritional status over the long-term storage (Bajaj et al., 2024). Therefore, this study aimed to examine the use of maltodextrin and pectin coatings, supplemented with lemongrass essential oils, applied to tomatoes.

MATERIALS AND METHODS

Materials

Servo F1 is a fresh tomato sourced from the Bandungan Garden located in Semarang Regency, Central Java, Indonesia. Fruits were harvested at the break-ripening stage and visually selected to ensure uniformity of size and shape, and freedom from physical damage or lesions, to minimise variability in the experimental material. Maltodextrin (MD) with dextrose equivalents (DE) of 10-12, used to produce the edible coating, was provided by Ensui Sugar Refining Co., Ltd. (Tokyo, Japan). Sigma-Aldrich (Jakarta, Indonesia) purchased glycerol (Gly), Tween 80, and pectin (9000-69-5 with 485 kDa). Atsiri House in Karanganyar, Indonesia, sells lemongrass essential oil (EO) with 99% purity.

Methods

Formulation of Edible Coating Solution

Dissolve 10 g of MD in 100 mL of distilled water and heat the mixture to 75°C on a hotplate. To prepare the edible coating solution, 2 mL of Gly, Tween 80 at a ratio of 1:2 (w/v), distilled water and EO at different ratios (0, 0.5, 1, 1.5, and 2% v/v) relative to the total volume of the coating solution were added. The solution was stirred continuously at 2000 rpm for 13 minutes to obtain a homogeneous solution using an Ultra Turrax Homogeniser (IKA T10). After mixing, 3 g pectin was added to the solution, and the mixture was heated and stirred for 10 minutes to obtain a homogeneous film solution.

Edible Coating Treatment of Tomatoes

The selected tomatoes should be of the same size, colour, and free from defects. After cleaning with water, the tomatoes were immersed in a chlorine solution for two minutes, rinsed with distilled water, and air-dried at room temperature. A total of 30 mL of coating solution was applied to each basket of 25 tomatoes (1.2 mL/fruit), and a hand sprayer was used to evenly coat the tomatoes. Before use or storage, the tomatoes are dried for twenty minutes at room temperature until they are no longer sticky.

Storage Conditions

After the coating treatment, all tomato samples were stored under controlled conditions. The fruits were stored at 4 °C and 30 °C with a controlled relative humidity (RH) of 75%, regulated by a saturation salt control system, for a 20-day storage period. The effect of the edible coating on post-harvest tomato quality was assessed based on observations collected on days 0, 5, 15, and 20 of storage. The parameters evaluated included shelf life, weight loss, firmness loss, skin colour change, microbial growth, and fruit damage level.

Fruit Remaining Weight Analysis

For each treatment group, fruit weight was measured with an analytical balance on days 0, 5, 10, 15, and 20. The initial weight (W_0) and the corresponding weight at time t (W_t) were recorded at each sampling interval. The amount of fruit weight loss (%) was calculated based on the relative reduction in weight over time, as described in Equation 1.

$$\text{Fruit weight loss (\%)} = \frac{W_0 - W_t}{W_0} \times 100\% \quad [1]$$

where W_0 is the initial weight, and W_t is the weight on the day. To express the proportion of weight retained by the fruit, the remaining weight (%) was calculated as shown in Equation 2.

$$\text{Remaining weight (\%)} = 100 - \text{fruit weight loss (\%)} \quad [2]$$

Fruit Firmness Analysis

Fruit firmness was determined using an analogue penetrometer (GY3, Y Wang Qiang, China) with a penetration depth of up to 10 mm. Measurements were taken at two different points on the fruit in each treatment group (Bejaei, 2022).

Colour Analysis

The surface colour was measured using a colourimeter (WR-10QC; FRU, China). The L^* (brightness), a^* (green-red colour intensity), and b^* (blue-yellow colour intensity) values resulting from the emission of specific wavelengths of light through the sample surface were based on the colour change of the sample. These values were obtained from the average of three readings taken approximately 120° apart to account for natural colour heterogeneity. The colour and absorbance of the sample indicate the concentration in the sample (Ruelas-Chacon et al., 2017). Before use, the WR-10QC colourimeter was calibrated using standard black and white calibration tiles. The reference values obtained were $X = 79.0$, $Y = 83.9$, and $Z = 87.9$.

Microbial Growth Analysis

A 25-gram sample was taken aseptically with a sterile scalpel and placed into a sterile container for microbiological analysis. Then, 225 mL of Butterfield phosphate buffer solution was added, and the mixture was homogenised for 2 minutes to achieve a 10^{-1} dilution. For the 10^{-2} dilution, 1 mL of homogenate was added to 9 mL of Butterfield phosphate buffer solution, and the next dilution (10^{-3}) was prepared by adding 1 mL of the 10^{-2} dilution and adding it to 9 mL of Butterfield phosphate buffer solution. For each dilution (10^{-1} , 10^{-2} , and 10^{-3}), one millilitre was pipetted into sterile Petri dishes in duplicate. Next, 15 mL was added to each plate for plate count (PCA) at 45 °C. To ensure proper mixing, the dish was shaken from side to side. The dish was stored in an inverted position in an incubator for 48 hours at 35 °C after solidification. A control was prepared without the sample by mixing the diluent with PCA (Siburian et al., 2021).

Fruit Damage Intensity Analysis

Subjective parameters were used to evaluate the degree of fruit damage. Observations were made by applying the damage intensity formula to each tomato fruit. The damage level was measured from 0 to 25%. Fruits with more than 25% damage were considered to have no marketable value and were removed from treatment. To classify fruit damage, the following grading scale was used: (0) no symptoms; (1) 1-5%; (2) 6-10%; (3) 11-15%; (4) 16-20%; and (5) 20-25%. Grading criteria included the presence of brown or black spots on the fruit surface, foul-smelling microbial infection, and severe softening due to internal tissue damage. Furthermore, the intensity of fruit damage can be calculated using the formula proposed by Townsend and Heuberger (1967), as cited by Kremer and Unterstenhofer (1967), as presented in Equation 3.

$$\text{Intensity of fruit damage (\%)} = \frac{\sum(n \times v)}{N \times V} \times 100 \quad [3]$$

where n is the number of fruits in each rating, v is the fruit damage scoring value, N is the total number of fruits used in one experimental unit, and V is the maximum score (5).

Statistical Analysis

SPSS Statistics 25 (IBM, USA) was used to statistically analyse the fruit quality measurement data. To ensure the reliability of the results, each measurement was performed three times ($n = 3$). To compare means and standard deviations (SD) at the significance level, Duncan's Multiple Range Test (DMRT) was used, with $p < 0.05$.

RESULTS AND DISCUSSION

The Impact of Incorporating Lemongrass Essential Oils into Maltodextrin-pectin Edible Coatings on the Weight Loss of Tomatoes

Physiological weight loss is one of the primary and prominent disorders of fresh produce and is caused by transpiration and respiration. Consistent weight loss was observed in tomato fruits during the storage period in all treatments. This may result from the physiological adaptation of tomato fruits to storage conditions and the optimisation of the coating effect after multiple applications. The weight loss of fruit coated with lemongrass essential oil is due to the oil layer acting as a barrier on the fruit's surface. The lipid layer reduces permeability to water vapour and respiratory gases, thus slowing the rate of mass loss due to transpiration. By inhibiting diffusion at the cuticle-air interface, this layer maintains water balance within the fruit. Although bioactive components can influence metabolic processes, weight loss is primarily due to the physical effects of the oil layer, which suppresses moisture loss. Figure 1 shows the effect of a maltodextrin-pectin-based edible coating with lemongrass essential oil on tomato weight loss. All samples exhibited gradual weight loss during storage. At 30 °C and 4 °C, all treatments showed significant weight loss, which began to appear on the fifth day after coating. Over the 20 days, weight loss was most pronounced during the ripening stage and storage. Tomatoes lose weight because of diminished synthesis before they are harvested (Shehata et al., 2021).

This was due to the continuous breakdown of carbohydrates into glucose and fructose. These are then converted to CO₂ and H₂O, which evaporate if they are not replaced. The application of an edible protective coating containing maltodextrin, pectin, and 2% lemongrass essential oil resulted in the lowest weight loss; the control treatment showed the highest weight loss, reaching 0.14% at 30 °C and 0.11% at 4 °C after 20 days.

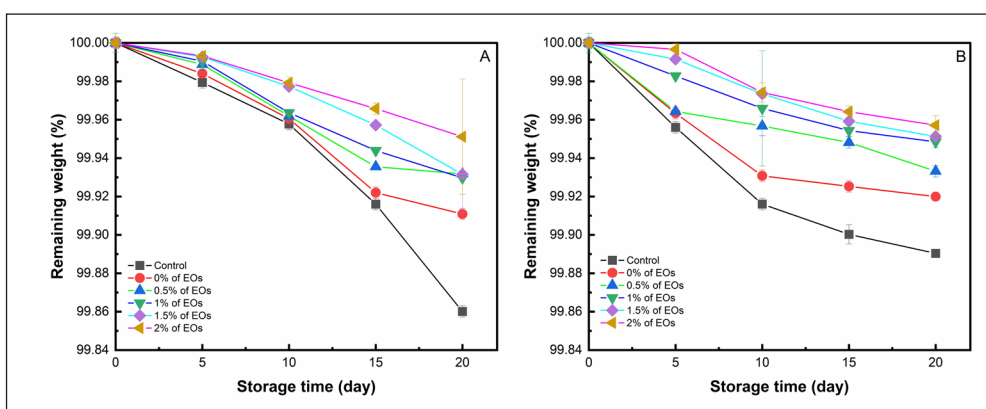


Figure 1. Effect of different concentrations of lemongrass EOs on the remaining weight (%) of tomatoes coated with maltodextrin-pectin during storage at (A) 30 °C and (B) 4 °C. Points represent the means, and error bars show SD

This is because of the hydrophobic nature of lemongrass essential oil, which restricts the movement of water vapour, and its antimicrobial nature, which inhibits the growth of fungi and bacteria (Praseptianga et al., 2017).

Differences in the rate of weight loss at various storage temperatures indicated that a low temperature of 4 °C was more effective in reducing the shrinkage process in tomatoes. The application of an edible coating consisting of maltodextrin-pectin and lemongrass essential oil to tomatoes during cold storage prevents them from losing weight. This is due to respiration and transpiration, which remove substrate and water from the body. In a study conducted by Sucheta et al. (2019), an edible protective film made from commercial pectin, cornstarch, and beetroot powder reduced oxygen (O₂) levels during the first 15 days of storage. Carbon dioxide (CO₂) concentrations increased between days 15 and 20 of storage. According to Fagundes et al. (2015), a similar trend was observed in cherry tomatoes stored at low temperatures. This suggests that storing fresh fruit in a climate with a film coating can affect oxygen and carbon dioxide concentrations within the fruit while maintaining high water content. Due to the faster water loss in uncoated fruit, stress on the fruit can be reduced.

Effect of Incorporating Lemongrass EOs into Maltodextrin-pectin Edible Coatings on the Firmness of Tomatoes

Although both coated and uncoated tomatoes showed a decrease in firmness during storage, uncoated fruits showed a significant decrease in firmness ($p < 0.05$) within 20 days of storage (Figure 2). This can be attributed to rapid ripening, which results in rapid softening. According to Ali et al. (2010), the decrease in firmness as fruit ripening progresses is caused by the degradation of cell structure, cell wall composition, and intracellular materials.

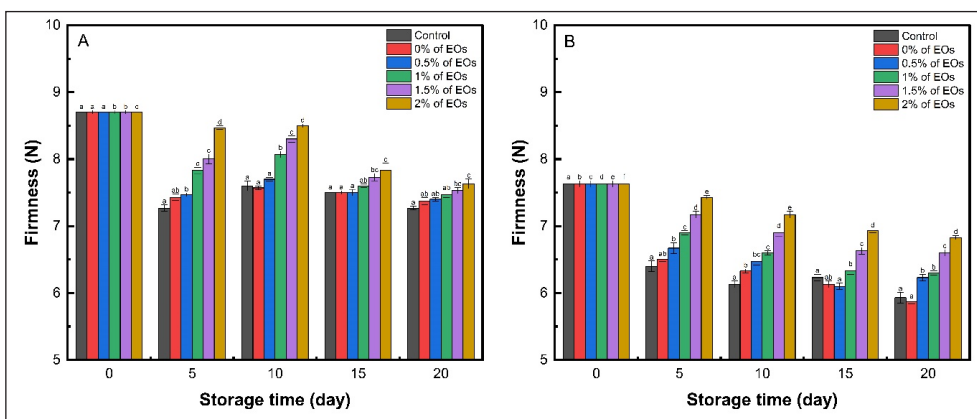


Figure 2. Effect of different concentrations of lemongrass EOs on the firmness of tomatoes coated with maltodextrin-pectin during storage at (A) 30 °C and (B) 4 °C. The values are presented as mean \pm standard deviation of three replicates ($n = 3$). Means with different lowercase superscripts within the same column indicate significant differences between the film samples ($p < 0.05$)

This study showed that the firmness of tomatoes coated with an edible protective coating and infused with lemongrass essential oil significantly affected their quality during storage. However, this effect was not observed in the control group. Although the control group did not show a significant difference, Duncan's test indicated otherwise. It was determined that the main factor contributing to the daily changes in tomato samples was damage. The data showed an increase in firmness from five to ten days of storage, followed by a decrease until the end of the storage period. The addition of lemongrass essential oil resulted in a significant change from the first to the fifth day. However, treatments with 1% and 1.5% lemongrass essential oil did not differ from the treatment with 2% lemongrass essential oil. The results demonstrated that at both 30 °C and 4 °C, the samples without the edible coating underwent the most significant changes in firmness compared to those with the coating. Edible coatings that minimise weight loss are more effective in preserving fruit texture, particularly firmness, which is closely linked to the water content (Mohd Suhaimi et al., 2021). Perdana et al. (2021) reported that the addition of EOs to film-forming solutions can reduce water vapour permeability. The reduction in water vapour permeability is associated with the hydrophobic properties of the edible coating. The addition of EOs enhanced the hydrophobic nature of the coating, resulting in lower respiration and transpiration rates, thereby extending the shelf life of the fruit. This study found that adding lemongrass EOs caused less textural alteration in tomatoes, especially when higher concentrations of the EOs were used.

Effect of Incorporating Lemongrass EOs into Maltodextrin-pectin Edible Coatings on the Microbial Growth in Tomatoes

Microorganisms such as bacteria, moulds, and yeasts are the primary culprits behind food spoilage, particularly in perishable items with a limited shelf life after harvest. If fruit becomes contaminated and microorganisms grow in it, this can cause a number of changes, such as unpleasant odours, shifts in taste, and unexpected colour changes.

Figure 3 shows a clear difference in microbial growth on tomatoes coated with maltodextrin-based edible coatings and pectin enriched with lemongrass essential oil during 20 days of storage at 30 °C and 4 °C. Microbial growth was faster at 30 °C than at 4 °C because environmental factors significantly influenced microbial activity. A temperature of 30 °C is within the optimal range for the growth of mesophilic microorganisms on fruits, such as bacteria and fungi that cause decay (Perdana et al., 2021). This situation causes microbial activity to increase rapidly, thus accelerating cell growth and the colonisation process on the fruit surface. Furthermore, high storage temperatures accelerate ripening and senescence in tomatoes, weakening their cell structure and increasing nutrient availability for microorganisms (Joaquina et al., 2013). This creates an environment which favors the growth and metabolism of microorganisms.

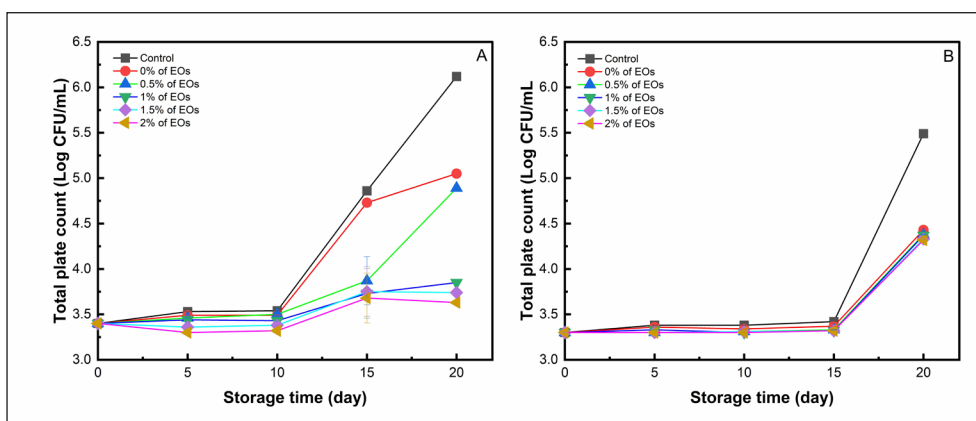


Figure 3. Effect of different concentrations of lemongrass EOs on the microbial growth profile on tomatoes coated with maltodextrin-pectin during storage at (A) 30 °C and (B) 4 °C

Alternatively, 4 °C is lower than the ideal temperature for the growth of microbes causing spoilage; therefore, it inhibits microbial growth and metabolism. These results support the findings by Fagundes et al. (2015) that low temperatures have better results in hindering the microbial growth on fruits. The control group displayed greater microbial growth at both temperatures. Thus, it was clear that adding lemongrass essential oils to maltodextrin-pectin edible coatings has inhibitory effects on microbial growth in fruits. Greater amounts of the lemongrass essential oil at higher concentrations (e.g., 1%, 1.5%, and 2%) at 30 °C and 4 °C had a better inhibitory effect on microorganisms compared to other groups. This result was attributed to the presence of certain compounds within lemongrass EOs that inhibit microbial growth in fruits.

Some of the important chemical components in lemongrass EO include citronellol, d-limonene, and lemongrass, which can inhibit the growth of *Listeria monocytogenes* bacteria in fruits by killing microorganisms (Faheem et al., 2022). Microorganism activity was inhibited using lemongrass EOs on edible films based on maltodextrin-pectin at high concentrations. Some components of EOs are more effective in inhibiting microorganisms if used in high amounts (Perdana et al., 2021).

Conversely, the reduction in visible microbial symptoms, such as the appearance of a foul odour and the spread of lesions, is likely due to the natural bioactivity of lemongrass essential oil. The monoterpene content of this oil, particularly its citral-rich component, provides antimicrobial and antioxidant properties. Research findings indicate that these characteristics inhibit surface colonisation and slow lesion development, thus complementing the moisture-reducing effect of the oil films. The more targeted and sustained inhibition of microbial growth, exceeding the effect of reducing water loss, suggests the involvement of chemical mechanisms in addition to the physical function of the films.

Effect of Incorporating Lemongrass EOs into Maltodextrin-pectin Edible Coatings on the Colour Change of Tomatoes

Colour is one of the primary sensory attributes of fresh fruits and vegetables, and significantly influences consumer acceptance. Furthermore, colour serves as an important indicator for assessing quality during storage and can be used to monitor the degradation and ageing processes in food products. Table 1 presents changes in tomato colour values based on the colourimetric parameters L^* , a^* , and b^* . The findings show that the brightness level (L^*) of the tomato fruit contributes to the conservation process during 20 days of storage at a temperature of 30 °C. There was a significant difference in the levels of L^* brightness among treatments with different concentrations of lemongrass essential oils (0, 0.5, 1, 1.5, and 2%). The control treatment exhibited the highest decrease in lightness, showing that the tomato fruit became darker. Analysis of the a^* colour test for tomatoes using edible coatings showed considerable variations in the a^* value during storage. The tomato fruits treated with 0%, 0.5%, and 1% lemongrass EOs recorded higher a^* values compared to the control group on day five. However, on day 10, samples with 1% lemongrass EOs had increased in a^* , and those with 0% and 0.5% lemongrass EOs also registered increases in their a^* values. The yellowness and blueness of tomato fruits were found to be significantly affected by various treatments after 20 days of storage at 30 °C. Significant variations were noted among 0%, 1.5%, and 2% lemongrass EOs treatments.

Observations of the colour of tomatoes stored at 4 °C showed a decrease in brightness (L^*) and a shift in colour value toward blue-yellow (b^*) with storage duration. Horticultural products, particularly tropical fruits, are generally susceptible to low temperatures. At cold temperatures, some metabolic processes slow down and can even stop if the temperature exceeds a critical limit that disrupts metabolic balance. This condition can lead to the limitation of molecules that are important for certain reactions and the accumulation of harmful compounds, which ultimately triggers cell damage, such as the appearance of brown spots. Polyphenol oxidase (PPO) contributes to this process by converting phenolic compounds into quinones, which then form brown pigments (Ferreira Holderbaum et al., 2010).

From the results obtained, it is clear that the edible coating made up of maltodextrin and pectin, in combination with different amounts of lemongrass essential oils, resulted in a more prolonged colour change compared to the control treatment of the edible coating alone. Respiration is also a factor in tomato fruit colour change. Tomatoes with inhibited respiration rates tend to experience minimal colour change due to the surface layer, whereas more pronounced colour changes occur when respiration is increased. The use of an edible coating made from maltodextrin-pectin with the addition of 2% lemongrass essential oil has been shown to cause only minor colour changes in tomatoes. This coating forms a semi-permeable barrier on the fruit's surface that can limit gas exchange, suppress respiration rates, and slow the ripening process.

Table 1

Changes in colour parameters of tomatoes with different concentrations of lemongrass EOs incorporated into maltodextrin-pectin edible coating during storage at 30 °C and 4 °C

Treatment	Storage at 30 °C				
	0 day	5 day	10 day	15 day	20 day
Colour Parameter: <i>L</i>*					
Control	49.34 ^a ± 0.06	44.78 ^a ± 0.19	37.41 ^a ± 0.20	37.42 ^a ± 0.16	35.31 ^a ± 0.18
0% of EOs	45.13 ^b ± 0.11	44.13 ^a ± 0.01	43.45 ^b ± 0.14	40.00 ^a ± 0.39	35.12 ^a ± 0.29
0.5% of EOs	47.04 ^{ab} ± 0.01	45.47 ^a ± 0.12	40.93 ^{ab} ± 0.02	38.79 ^a ± 0.06	38.32 ^a ± 0.24
1% of EOs	46.52 ^{ab} ± 0.05	46.38 ^a ± 0.41	41.43 ^{ab} ± 0.09	38.10 ^a ± 0.01	35.86 ^a ± 0.08
1.5% of EOs	47.43 ^{ab} ± 0.13	42.83 ^a ± 0.16	41.67 ^{ab} ± 0.20	41.51 ^a ± 0.04	39.45 ^a ± 0.10
2% of EOs	45.73 ^b ± 0.09	45.63 ^a ± 0.14	42.71 ^b ± 0.01	42.34 ^a ± 0.01	41.51 ^a ± 0.06
Colour Parameter: <i>a</i>*					
Control	3.21 ^c ± 0.04	6.40 ^b ± 0.03	6.42 ^b ± 0.03	6.45 ^b ± 0.02	9.34 ^c ± 0.16
0% of EOs	4.71 ^d ± 0.01	5.65 ^c ± 0.00	6.04 ^b ± 0.21	6.05 ^b ± 0.20	7.35 ^d ± 0.03
0.5% of EOs	3.12 ^a ± 0.01	3.22 ^a ± 0.00	3.66 ^a ± 0.41	3.74 ^a ± 0.43	6.68 ^a ± 0.23
1% of EOs	2.67 ^c ± 0.01	3.14 ^d ± 0.08	4.19 ^c ± 0.20	4.20 ^c ± 0.20	5.15 ^c ± 0.00
1.5% of EOs	2.78 ^b ± 0.06	3.33 ^a ± 0.09	3.37 ^a ± 0.07	3.47 ^a ± 0.02	4.12 ^b ± 0.16
2% of EOs	2.57 ^f ± 0.01	2.87 ^e ± 0.02	3.77 ^d ± 0.00	3.77 ^d ± 0.00	3.84 ^f ± 0.02
Colour Parameter: <i>b</i>*					
Control	19.72 ^a ± 0.15	19.06 ^a ± 0.29	14.35 ^a ± 0.04	12.50 ^a ± 0.02	12.36 ^a ± 0.02
0% of EOs	21.07 ^b ± 0.04	20.53 ^b ± 0.07	19.99 ^b ± 0.40	12.47 ^a ± 0.02	11.73 ^a ± 0.12
0.5% of EOs	19.58 ^a ± 0.07	17.16 ^c ± 0.01	17.01 ^c ± 0.27	13.95 ^b ± 0.08	12.99 ^b ± 0.03
1% of EOs	19.36 ^a ± 0.11	17.83 ^c ± 0.15	16.05 ^c ± 0.04	14.67 ^b ± 0.01	9.30 ^c ± 0.01
1.5% of EOs	21.88 ^c ± 0.25	21.60 ^d ± 0.05	16.82 ^c ± 0.19	15.77 ^c ± 0.03	9.96 ^c ± 0.03
2% of EOs	20.94 ^b ± 0.03	20.63 ^b ± 0.06	17.56 ^c ± 0.07	13.53 ^b ± 0.07	7.31 ^d ± 0.05
Treatment	Storage at 4 °C				
	0 day	5 day	10 day	15 day	20 day
Colour Parameter: <i>L</i>*					
Control	39.08 ^a ± 0.04	38.42 ^a ± 0.14	38.23 ^a ± 0.00	34.68 ^a ± 0.13	33.64 ^a ± 0.11
0% of EOs	39.12 ^a ± 0.04	38.90 ^a ± 0.01	38.42 ^a ± 0.37	36.22 ^a ± 0.08	35.63 ^a ± 0.00
0.5% of EOs	36.25 ^b ± 0.18	34.36 ^b ± 0.06	33.48 ^b ± 0.00	33.44 ^b ± 0.00	32.43 ^b ± 0.10
1% of EOs	38.84 ^a ± 0.00	35.16 ^b ± 0.00	34.90 ^b ± 0.05	33.75 ^b ± 0.00	33.40 ^b ± 0.10
1.5% of EOs	35.36 ^b ± 0.02	35.30 ^b ± 0.13	34.76 ^b ± 0.01	34.09 ^b ± 0.00	32.85 ^b ± 0.09
2% of EOs	35.47 ^b ± 0.01	35.30 ^b ± 0.10	34.50 ^b ± 0.00	32.61 ^b ± 0.00	32.57 ^b ± 0.03
Colour Parameter: <i>a</i>*					
Control	6.68 ^b ± 0.23	3.74 ^c ± 0.43	3.66 ^c ± 0.41	3.22 ^c ± 0.00	3.12 ^c ± 0.01
0% of EOs	4.28 ^c ± 0.16	3.47 ^c ± 0.02	3.37 ^c ± 0.07	3.33 ^c ± 0.09	3.21 ^c ± 0.01
0.5% of EOs	4.12 ^c ± 0.16	3.47 ^c ± 0.02	3.37 ^c ± 0.07	3.33 ^c ± 0.09	3.21 ^c ± 0.01
1% of EOs	3.94 ^c ± 0.16	6.45 ^{ab} ± 0.02	6.42 ^{ab} ± 0.03	6.40 ^{ab} ± 0.03	6.68 ^{ab} ± 0.04
1.5% of EOs	7.35 ^{ab} ± 0.03	6.06 ^{abc} ± 0.20	6.04 ^{abc} ± 0.21	5.65 ^{abc} ± 0.00	4.71 ^{abc} ± 0.01
2% of EOs	5.55 ^{bc} ± 0.16	4.00 ^{bc} ± 0.20	3.77 ^c ± 0.00	2.87 ^c ± 0.02	3.84 ^c ± 0.01

Table 1 (continued)

Treatment	Storage at 30 °C				
	0 day	5 day	10 day	15 day	20 day
Colour Parameter: <i>b</i>*					
Control	22.92 ^a ± 0.62	17.84 ^c ± 0.62	15.47 ^d ± 0.62	15.25 ^d ± 0.62	15.10 ^d ± 0.62
0% of EOs	16.42 ^c ± 0.60	16.50 ^c ± 0.60	15.76 ^c ± 0.60	14.35 ^c ± 0.60	13.25 ^c ± 0.60
0.5% of EOs	28.71 ^b ± 1.00	19.46 ^c ± 1.00	19.23 ^c ± 1.00	19.08 ^c ± 1.00	14.67 ^c ± 1.00
1% of EOs	14.96 ^f ± 0.60	17.10 ^d ± 0.60	17.05 ^d ± 0.60	17.03 ^d ± 0.60	14.90 ^d ± 0.60
1.5% of EOs	17.11 ^d ± 0.60	14.94 ^f ± 0.60	14.81 ^f ± 0.60	14.50 ^f ± 0.60	14.35 ^f ± 0.60
2% of EOs	14.55 ^e ± 0.60	14.39 ^e ± 0.60	13.13 ^e ± 0.60	11.00 ^e ± 0.60	9.22 ^e ± 0.60

Note. *Values are presented as mean ± standard deviation from three replicates (n = 3). Means with different lowercase superscripts within the same column indicate significant differences between the film samples (p < 0.05)

As a polysaccharide-based coating, maltodextrin-pectin forms a hydrocolloid matrix that inhibits air movement between the fruit and the external environment. This condition changes the internal environment of the fruit, delaying respiration and ripening processes. Furthermore, the combination of hydrocolloids and lipids produces a coating that is effective in reducing respiration rates while reducing water loss.

The use of an edible coating made of maltodextrin-pectin with lemongrass EOs has proven to be highly effective in terms of preventing the colour change in tomatoes as compared to non-coated control products. It seems that better colour preservation and lesser tissue destruction can be attributed to a combined effect of the oil film and the biological actions of lemongrass EOs. The oil coating acts as a barrier against oxygen transport and moisture stress, thus inhibiting the oxidation process and preventing tissue softening. At the same time, the antioxidants present in lemongrass EOs can slow down oxidising processes leading to pigment and membrane destruction, while the antimicrobial activities can prevent lesion formation. Collectively, these synergistic mechanisms minimise discolouration and decrease tissue damage during storage. The oil layer inhibits degradation caused by oxidation and moisture, whereas the antioxidant and antimicrobial properties of lemongrass essential oil help maintain cell integrity and prevent lesion development.

Figure 4 depicts the physical appearance of the tomatoes after coating with the edible coating at various storage temperatures: (A) 30 °C and (B) 4 °C. At the 30 °C storage temperature, the tomato colour changed to completely red on the 20th day, suggesting that the tomato had fully matured. In contrast, the coated tomatoes showed delayed ripening, with increased effectiveness observed at higher concentrations of lemongrass essential oil, as evidenced by the persistence of a yellowish colour at the end of the storage period. The colour change under edible coating treatment at 4 °C storage temperature showed a significant difference between the control and the maltodextrin-pectin coating with lemongrass essential oil.

Control fruits changed colour from green to yellow at the end of the storage period, but the coated samples showed a clear delay in colour change during storage. Maltodextrin-pectin coating with lemongrass essential oil significantly delayed chlorophyll degradation and ripening (Figure 4). The coated fruit maintained a predominantly green-yellow colour for up to 20 days, whereas yellow to reddish colouration was observed at 30 °C. Edible coatings made of maltodextrin-pectin combined with varying concentrations of lemongrass essential oil significantly affected colour change. The storage temperature is also important for maintaining fruit colour and quality throughout the storage period. These results are consistent with research conducted by Adjouman et al. (2018), which showed that the polysaccharide layer helps limit the increase in the a^* value of tomatoes compared to the control group. This phenomenon is likely due to the layer inhibiting oxygen exchange (Olivas et al., 2007). Due to their structural properties, polysaccharides such as maltodextrin and pectin act as oxygen barriers (Fagundes et al., 2014). The respiration rate is influenced by the amount of available oxygen, so the effectiveness of this layer in limiting oxygen diffusion is crucial. Qualities such as firmness and retardation of colour change are maintained by this layer, both of which are strongly influenced by respiration (Fagundes et al., 2014). Furthermore, storing tomatoes at low temperatures is crucial for maintaining their quality because cold conditions inhibit the genes responsible for carotenoid biosynthesis, which helps maintain carotenoid content and prolong freshness (Li et al., 2021).



Figure 4. Effect of different concentrations of lemongrass EOs on the physical changes in tomatoes coated with maltodextrin-pectin before and after storage at (A) 30 °C and (B) 4 °C

Effect of Incorporating Lemongrass EOs into Maltodextrin-pectin Edible Coatings on the Intensity of Tomato Fruit Damage

Variations in the severity of damage to tomato fruits are shown in Table 2. The table highlights significant differences in the intensity of damage to tomatoes stored at 30 °C and 4 °C, as well as the impact of maltodextrin-pectin-based edible protective coatings with varying concentrations of lemongrass essential oil over a 20-day period. These findings indicate that the intensity of damage to tomato fruits is significantly influenced by storage temperature and the use of edible protective coatings. Fruit damage increased gradually during storage at 30 °C, with the control group reaching 20.4% on day 20. However, treatment using a maltodextrin-pectin coating enriched with lemongrass essential oil significantly reduced the damage level. The 2% concentration showed the best results with a damage level of only 9.9% at 4 °C, whereas the control group at that temperature recorded damage of 0.9% on day 20. In addition, throughout the storage period, the samples with the addition of 1%, 1.5%, and 2% lemongrass essential oil did not experience damage.

Low storage temperature will slow down the process of degradation and metabolism. As such, physiological decline and microbial growth will be greatly minimised (Alqahtani et al., 2025).

Table 2

Effect of different concentrations of lemongrass EOs on the intensity of damage observed in tomato fruit coated with a maltodextrin-pectin during storage at 30 °C and 4 °C

Treatment	Intensity of Fruit Damage (%)				
	Storage at 30 °C				
	0 day	5 day	10 day	15 day	20 day
Control	0 ^a ± 0.00	0.9 ^a ± 0.00	4.2 ^a ± 0.00	11.7 ^a ± 0.00	20.4 ^a ± 0.00
0% of EOs	0 ^a ± 0.00	1.5 ^b ± 0.00	4.2 ^a ± 0.00	6.0 ^b ± 0.00	19.2 ^a ± 0.00
0.5% of EOs	0 ^a ± 0.00	0.6 ^c ± 0.00	3.6 ^b ± 0.00	9.9 ^c ± 0.00	12.6 ^b ± 0.00
1% of EOs	0 ^a ± 0.00	0.6 ^c ± 0.00	3.6 ^b ± 0.00	6.0 ^b ± 0.00	12.6 ^b ± 0.00
1.5% of EOs	0 ^a ± 0.00	0.3 ^d ± 0.00	1.2 ^c ± 0.00	3.6 ^c ± 0.00	10.8 ^c ± 0.00
2% of EOs	0 ^a ± 0.00	0.3 ^d ± 0.00	1.2 ^c ± 0.00	3.6 ^c ± 0.00	9.9 ^c ± 0.00
Treatment	Intensity of fruit damage (%)				
	Storage at 4 °C				
	0 day	5 day	10 day	15 day	20 day
Control	0 ^a ± 0.00	0 ^a ± 0.00	0.6 ^a ± 0.00	0.6 ^a ± 0.00	0.9 ^a ± 0.00
0% of EOs	0 ^a ± 0.00	0 ^a ± 0.00	0 ^a ± 0.00	0.3 ^b ± 0.00	0.3 ^b ± 0.00
0.5% of EOs	0 ^a ± 0.00	0 ^a ± 0.00	0 ^a ± 0.00	0 ^a ± 0.00	0.3 ^b ± 0.00
1% of EOs	0 ^a ± 0.00	0 ^a ± 0.00	0 ^a ± 0.00	0 ^a ± 0.00	0 ^a ± 0.00
1.5% of EOs	0 ^a ± 0.00	0 ^a ± 0.00	0 ^a ± 0.00	0 ^a ± 0.00	0 ^a ± 0.00
2% of EOs	0 ^a ± 0.00	0 ^a ± 0.00	0 ^a ± 0.00	0 ^a ± 0.00	0 ^a ± 0.00

Note. *Values are presented as mean ± standard deviation from three replicates (n = 3). Means with different lowercase superscripts within the same column indicate significant differences between film samples (p < 0.05)

The edible coating, made from maltodextrin and pectin, serves as both a physical and gaseous barrier to prevent water loss and gas exchange, which can cause loss of fruit quality. Lemongrass essential oil enhanced the antimicrobial properties of the protective layer, providing additional protection against microbial spoilage. The significant difference in spoilage rates between the two storage temperatures indicates that temperature influences the metabolic processes and fruit degradation. Furthermore, physiological damage and microbial spoilage in tomatoes tend to increase with storage duration. Therefore, lowering the storage temperature can extend the shelf life of tomatoes while slowing the spoilage process (Shehata et al., 2021).

Tomatoes can be kept fresh for much longer periods using a protective film. The use of active agents from lemon grass essential oil in edible protective film consisting of maltodextrin and pectin will improve fruit protection. Pectin enhances the gas barrier properties of the protective coating, whereas maltodextrin forms a thin film that acts as a physical barrier and adds mechanical strength to the protective coating (Mohd Suhaimi et al., 2021). Lemongrass essential oil, as an active component, enhances the protective coating of edible tomatoes and extends their shelf life. Lemongrass essential oil also acts as an antimicrobial agent.

CONCLUSION

An edible protective film composed of 10% maltodextrin and 3% pectin exhibited excellent stability and effectively transported lemongrass essential oil. Tomato quality during storage, including colour, weight retention, firmness, and microbial control, was improved by adding lemongrass essential oil (0-2%) to this matrix. Storage at 4 °C resulted in better preservation than storage at 30 °C. This resulted in slower ripening, reduced moisture loss and tissue damage. The barrier properties of the protective layer and the antioxidant and antimicrobial effects of lemongrass essential oil caused this shrinkage. A 2% lemongrass essential oil formulation has been shown to increase preservation effectiveness and maintain fruit quality during storage. The results showed that a maltodextrin-pectin-based coating enriched with lemongrass essential oil could extend the shelf life of tomatoes. For application to various commodities, further research should focus on optimising the material composition, analysing sensory impacts, and evaluating its performance.

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