JOURNAL OF HORTICULTURE AND POSTHARVEST RESEARCH
2025, VOL. 8(3), 317-334

Journal of Horticulture and Postharvest Research

Journal homepage: www.jhpr.birjand.ac.ir

University of Birjand

Effects of methylcellulose coating with citrus essential oils on the quality of tomato fruits during storage

Ahad Sheikh Yousefi[1], Orang Khademi[1] and Ayatollah Rezaei[1,*]

1, Department of Horticulture, Faculty of Agriculture, Shahed University, Tehran, Iran

ARTICLE INFO

Original Article

Article history:
Received 20 September 2024
Revised 26 December 2024
Accepted 28 December 2024

Keywords:
Appearance quality
Edible coating
Food security
Postharvest losses
Shelf life

DOI: 10.22077/jhpr.2025.8155.1423
P-ISSN: 2588-4883
E-ISSN: 2588-6169

***Corresponding author:**
Department of Horticulture, Faculty of Agriculture, Shahed University, Tehran, Iran.
Email: arezaei@shahed.ac.ir

ABSTRACT

Purpose: Highly perishable tomatoes face rapid deterioration at postharvest. This study investigated the effect of methylcellulose (MC) edible coating and citrus essential oil (EO) on disease control and postharvest quality preservation of tomatoes. **Research Method:** The experimental factors included MC at three levels (0, 0.5, and 1% (w/v)), citrus EO (control, orange, and sour orange EO, at concentration of (1 g/L), and studying time (ST) (7, 14, and 21 days). The treated fruits were stored at 10°C with RH over 80±5% and evaluated for disease severity and other fruit quality attributes during storage. **Findings:** The results showed that both MC and EO treatments effectively controlled tomato fruit disease and maintained its marketability throughout the experiment, with the combination of these treatments yielding better results. The applied treatments, especially 1% MC, reduced weight loss compared to control. The results indicated increase in coloring of samples during the experiment. The firmness of the fruit tissue decreased over time, and the EO treatment proved to be more effective than MC in preserving fruit firmness. Applying MC and EO treatments, either alone or in combination, preserved total soluble solids compared to the control samples. **Research limitations:** No limitations were encountered. **Originality/Value:** Based on the results of this experiment, incorporating EO into MC edible coating showed promise in extending the shelf life of tomatoes by controlling weight loss, rate of metabolism, and disease severity. This approach offers a sustainable and effective alternative to traditional chemical treatments while providing consumers with a healthier and more flavorful product.

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is a climacteric fruit with a short shelf life after ripening (Park et al., 2018). Storing some tomato production for off seasons becomes necessary since they cannot all be sold during the production season. However, tomato fruits are prone to severe weight loss, quality deterioration, and fungal contamination after harvest. Therefore, there is a need for treatments that can control weight and quality loss while also having antimicrobial properties (Thole et al., 2020). Postharvest diseases of fresh produce can occur during harvesting, sorting, packaging, storage, and transportation to markets. These diseases can develop at normal room temperatures or even in refrigeration. If the produce is stored in refrigeration, the diseases continue to expand until the product is consumed (Elik et al., 2019). In most cases, postharvest diseases are caused by fungi of the genera *Botrytis*, *Aspergillus*, and *Penicillium*. Even in areas with advanced warehouses using high technology, these fungi can still damage fruits, sometimes causing up to 50% damage (Alegbeleye et al., 2022).

The use of natural preservatives as an alternative to chemical preservatives has grown due to consumers wanting to use natural and safer products (Mesías et al., 2021; Moradinezhad & Firdous, 2025). Among the natural substances that can be used as preservatives in food are essential oils (EOs) and plant extracts. EOs, produced by plants as part of their secondary metabolism, possess many biological effects, including the potential to kill bacteria, fungi, and yeasts (Angane et al., 2022). In the natural world, EOs defend against biotic stresses while attracting pollinating insects, contributing to plant survival and evolution (Raguso, 2020). The active ingredient in plant EOs, is less than 1% of the dry weight of the plant (Ni et al., 2021). Plant EOs are mixtures of compounds produced by living organisms and are obtained through physical means such as distillation from the whole plant or parts of the plant. These fragrant, oily, and easily evaporated plant compounds are produced and stored in specialized secretory structures within various plant parts, such as leaves, flowers, fruits, buds, and stems. They are not always chemically uniform and often involve terpenes (Butnariu, 2021). Citrus EO is considered one of the most important raw materials for flavoring foods and beverages. A total of 21 compounds have been identified in citrus EO, with limonene (94.3%), myrcene (1.5%), linalool (0.9%), decanal (0.5%), alpha-pinene (0.4%), and octanol (0.3%) being the most prominent (González-Mas et al., 2019). Research shows that citrus EO may inhibit pathogen growth in postharvest diseases (Simas et al., 2017). Recently, limonene, a natural citrus compound, has gained attraction due to its versatile applications in food flavoring, green chemistry, pharmaceuticals, and sustainable pathogen and pest control. It's a biodegradable and non-toxic alternative to traditional chemicals, offering eco-friendly solutions (Satari & Karimi, 2018).

Proper packaging is key to reducing waste and preserving the quality and shelf life of horticultural crops during postharvest handling (Rahman et al., 2024). Covering fruits and vegetables with various films and edible coatings is important for packaging. Edible coatings form thin, protective layers that control food's moisture, oxygen, and solute transfer. Likewise, reducing moisture, oxidation, and respiration helps maintain quality and extend the shelf life of fresh products (Iñiguez-Moreno et al., 2024). Methylcellulose (MC) is a natural, colorless, odorless, and non-toxic polysaccharide coating (Kocira et al., 2021). MC edible coating has been applied to peaches, nectarines, apricots, peppers, avocados, citrus fruits, berries, and green beans (Suhag et al., 2020a). Edible coatings have emerged as a promising alternative to traditional chemical preservatives, offering a natural and environmentally friendly approach to extending shelf life and maintaining quality (Perez-Vazquez et al., 2023). Some studies have revealed that coatings, either alone or with natural compounds, extended the shelf life and maintained the quality of postharvest the particularly perishable foods including, tomatoes (Barbosa et al., 2021; Suhag et al., 2020b; Zhang et al., 2019). To our knowledge, no research has examined the effects of citrus EO-infused MC coating on postharvest tomato quality during storage. This study aims to investigate the effectiveness of the coating in prolonging shelf life and provide fundamental understanding for tomato preservation.

MATERIALS AND METHODS

Preparing samples, coating formulation and application

The experiment was carried out in the postharvest physiology and technology laboratory at Shahed University in 2022. Tomatoes (variety; SV8320TD, Seminis Company) at mature green stage were harvested and washed with tap water. Healthy and uniform fruits were selected for the experiment (Fig. 1). The fruit quality traits at harvest are presented in Table 1. The treatments applied included MC edible coating at three levels (zero as a control, 0.5%, and 1%) and EO at three levels (distilled water as a control, orange (Thomson Navel variety) and sour orange peel EOs, each one at a concentration of 1 g/L), as well as their combination.

The required amount of MC powder was weighed and completely dissolved in one liter of 70% methanol while heating to prepare the edible coating. After cooling, the EO was dissolved in the edible coating solution and used for treatment. The EOs from fresh citrus peels (40 g) were prepared by hydrodistillation using a Clevenger-type apparatus (Aria Exir, Iran), for 3 hours. To remove any remaining moisture, the obtained EOs underwent dehydration with the aid of sodium sulfate and was subsequently stored at a temperature of 4°C (Chanthaphon et al., 2018). The EOs extracted from citrus peel exhibited a distinct yellow color, and the yield of the extracted EOs was determined to be 1.2% (w/w).

The fruits were immersed in the solutions prepared from the edible coating of MC and EOs for 10 minutes. They were then transferred to a dry room at 10°C with a relative humidity above 80%. At 7, 14, and 21 days, 21 fruits from each treatment were taken out of storage as three replicates and examined for disease percentage and quality indicators.

Evaluation of characters

The disease of tomato fruits was visually graded based on the severity of each fruit's disease, ranging from one (indicating the lowest amount of disease) to four (indicating the highest amount of disease). Similarly, the marketability of tomatoes was visually graded based on the appearance of each fruit, with scores ranging from one (indicating the lowest degree of marketability) to four (indicating the highest degree of marketability) (Jiang et al., 2010) (1):

$$\text{Marketability index} = \sum [(\text{degree of marketability}) \times (\text{number of fruits in each degree of marketability})] / (4 \times \text{total number of fruits in the treatment}) \quad (1)$$

Table 1. Traits of tomato fruit at the initial time before treatments.

Traits	L*	Hue angle	Firmness (kg/cm^2)	TSS (Brix°)	TA (%)
value	59	128	6.6	6.2	0.81

TSS: total soluble solids, TA: titratable acidity.

Fig. 1. Tomato fruit sample used in this experiment.

To measure the percentage of weight loss, a digital scale with an accuracy of 0.01 g was used to measure and record the initial weight of tomatoes on the day of the treatment. On the day of the investigation, each tomato was weighed again using the same digital scale, and the secondary weight was recorded. Then, the weight loss percentage was calculated using the following equation (2):

$$\text{Weight loss percentage} = (\text{initial weight} - \text{secondary weight}) / \text{initial weight} \times 100 \qquad (2)$$

A colorimeter (model 135 TES, Taiwan) was used to measure the color indices L*, a*, and b*. Random points on each tomato were measured using the colorimeter, and hue angle was calculated by the following equation (3) (Khademi et al., 2013):

$$Hue^* = \tan^{-1}(b^*/a^*) \qquad (3)$$

The texture firmness of each tomato was measured using a handheld firmness tester (GY-3 model) with a 4 mm diameter. The average texture firmness of the tomatoes was recorded and expressed as Kg/cm^{-2}.

A refractometer (model VBR80, Taiwan) was used to measure the TSS. A drop of tomato juice was placed on the prism of the refractometer, the amount of TSS was recorded and expressed in Brix°.

To measure the TA, 10 ml of filtered fruit extract was mixed with 90 ml of distilled water, bringing it to a final volume of 100 ml. The solution was then titrated with 0.1 N sodium hydroxide until it reached a pH of 8.2. The TA was calculated based on the predominance of citric acid using the relevant formula and expressed as percentage (Barzegar et al., 2018).

Data analysis

The experiment was conducted as a three-factor factorial in a completely randomized design with three replications. The experimental factors included edible coating treatment at three levels, EO treatment at three levels, and studying time (ST), at three levels. After checking the data for normality using SAS software (version 3.9), the data was analyzed, and the difference between the means was compared using the Least Significant Difference (LSD, P=0.05) test. Additionally, the standard deviation of the means was calculated.

RESULTS AND DISCUSSION

Disease

Based on the results of the analysis of variance (Table 2), the main effects of ST, edible coating, and EO, as well as the interaction effects between ST and EO, the interaction between edible coating and EO, and the triple interaction between the factors, on the percentage of disease were significant. However, the interaction effect between ST and edible coating on the disease percentage was insignificant.

The results showed that almost no disease was observed in most treatments on day 7 of the study. However, on day 14, the disease spread under the effect of most treatments, significantly increasing with the increase of storage time to 21 days. Samples without edible coating and EO treatment (control) had the highest disease percentage. On the other hand, applying EO and edible coating treatments reduced the disease percentage of tomato fruit. The lowest rate of disease was observed on tomatoes treated with 1% MC coating in combination with orange and sour orange EOs. In general, orange EO was more effective than sour orange EO in controlling tomato disease in this experiment (Fig. 2-A, Fig. 3).

Tomatoes can suffer from microbial decay due to fungal and bacterial rots, compromising quality and food safety. Edible coatings and the inclusion of antimicrobial compounds, such as plant extracts and EOs, have proven effective in minimizing this decay. For example, applying a chitosan-based coating with *Ruta graveolens* EO to ‘Chonto’ tomatoes preserved their quality by preventing mold growth, minimizing weight loss, and lowering the decay index during 14 days of storage compared to control (Peralta-Ruiz et al., 2020). A chitosan-grape seed extract coating effectively reduced disease by inhibiting *Salmonella* and total mesophilic aerobes and expanded the shelf life of cherry tomatoes (Won et al., 2018). According to Robledo et al. (2018) thymol incorporated into an edible film of quinoa protein/chitosan effectively inhibited the growth of *Botrytis cinerea* on tomatoes. It was also shown that *Aloe vera* gel alone or combined with sage EO decreased tomato fruit decay symptoms with more pronounced effects on low EO concentration (i.e., 0.1%) after 14 days of storage (Tzortzakis et al., 2019). In addition, the application of the *Aloe vera* gel with *Zataria multiflora* essential oil as a new edible coating on the apple fruit surface resulted in a delay in the severity and occurrence of diseases caused by *Botrytis cinerea* and *Penicillium expansum* (Oraee et al., 2025).

Table 2. Analysis of variance of the effect of MC coating and citrus EO on disease control and preserving tomato fruit quality during storage.

		Mean of squares							
Source of variations	df	Disease	Marketability	L*	Hue	Weight loss	firmness	TSS	TA
Studying time (ST)	2	2177.7**	0.11**	2600.5**	18216.4**	789.4**	3.4**	1.07**	0.43**
Methylcellulose (MC)	2	2088.6**	0.21**	28.3ns	1324.3**	275.8**	1.4*	1.76**	0.06*
Essential oil (EO)	2	1944.4**	0.16**	53.2*	529.1*	418.1**	7.6**	1.52**	0.002 ns
MC×ST	4	677.7 ns	0.021*	123.1**	1576.3**	141.9**	4.5**	1.72**	0.11**
EO×ST	4	1044.4**	0.057**	43.9**	913.7**	126.5**	0.4ns	0.35**	0.013 ns
EO×MC	4	1644.4**	0.073**	35.3*	312.7ns	251.1**	7.5**	2.16**	0.068**
EO×MC×ST	8	894.4**	0.06**	35.2**	199.5ns	79.5**	1.6**	1.28**	0.030*
Error	54	288.8	0.008	8.2	20.4	20.1	0.4	0.089	0.013

ns, *, and ** indicate non-significant, significant at 5% and 1% probability levels, respectively.

EOs are concentrated hydrophobic liquids that may inhibit microbes' growth by attaching to the phospholipid bilayer of their cell membrane through hydrophobic interactions, causing structural damage that ultimately leads to the death of cells. In addition, limonene, a principal constituent of citrus EO, possesses antimicrobial properties that should not be overlooked. Its lipophilic nature allows it to disrupt proteins and lipid layers, altering cell wall function and properties and causing the leakage of intracellular components, ultimately leading to cell death (Tzortzakis et al., 2019).

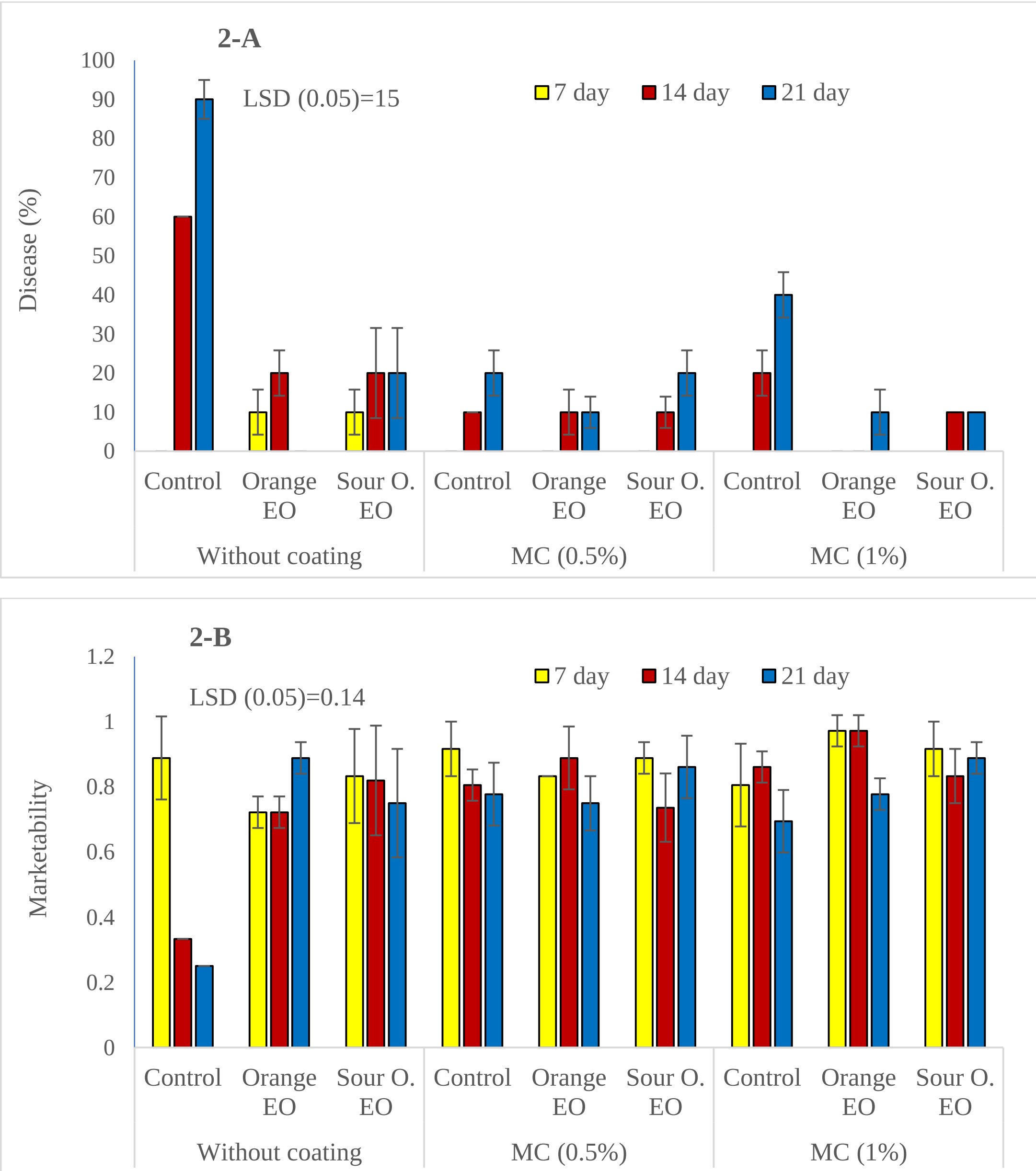


Fig. 2. The effect of MC edible coating and citrus EO on disease percentage (2-A) and marketability (2-B) of tomato fruit during storage at 10 °C with relative humidity ≥ 80%. Error bars represent the standard error of the mean of three replicates.

Marketability

The analysis of variance showed that the effects of ST, edible coating, and EO, as well as the effects of double and triple interactions between these factors on the marketability index of tomato fruit, were significant. The results of the means comparison also showed that the marketability of the fruits decreased over time in most of the treatments. The lowest degree of marketability among the samples was observed in fruits without MC edible coating and EO treatment (control). The application of MC edible coating treatments or EO, alone or in combination with each other resulted in proper preservation of the marketability of tomato fruit during this experiment. The highest degree of marketability was also observed in the MC 1% edible coating samples combined with orange EO (Fig. 2-B, Fig. 3).

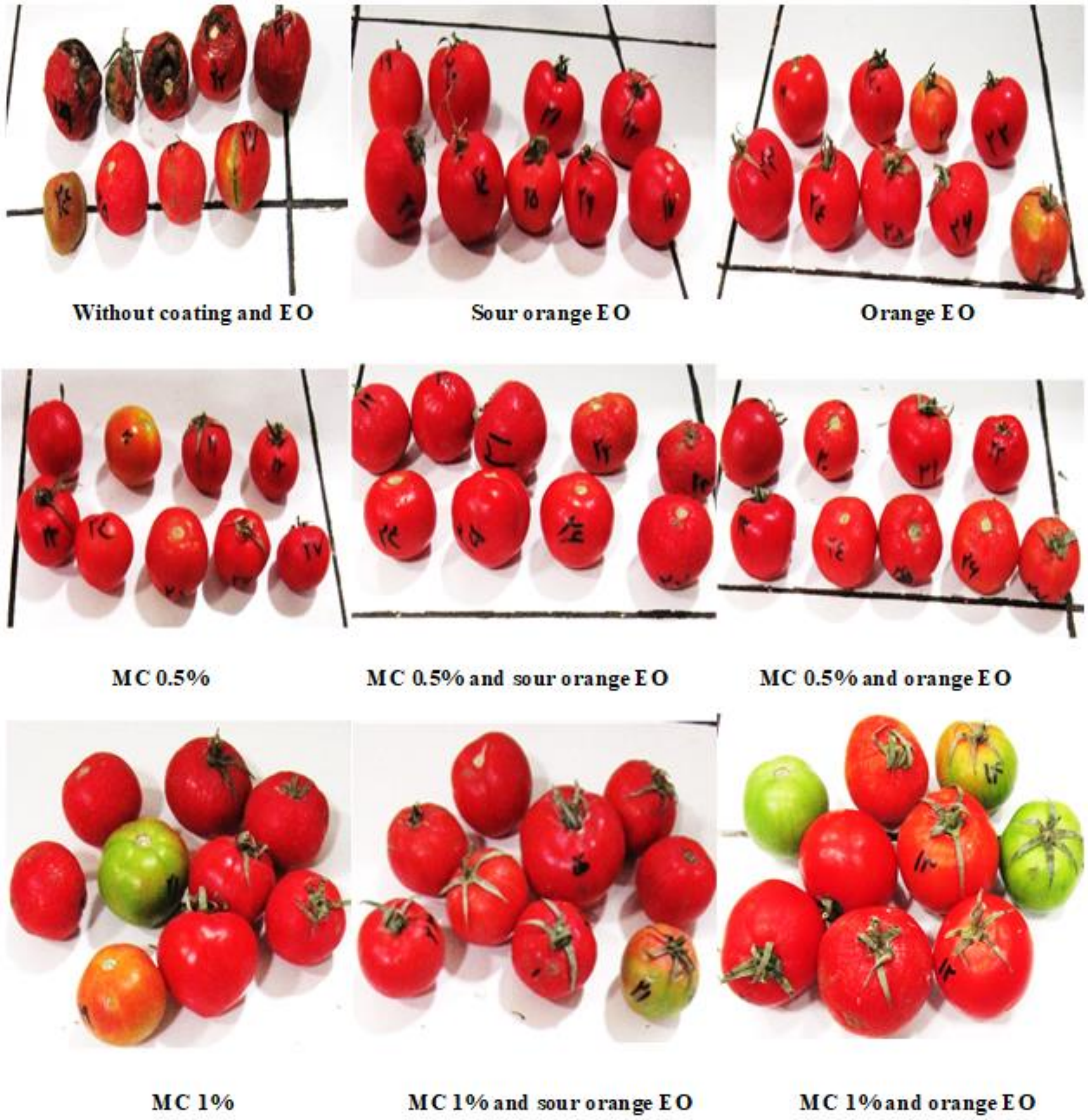


Fig. 3. The effect of MC edible coating and citrus EO in controlling the disease and maintaining tomato marketability for 14 days.

Using MC as a coating for strawberry fruit reduced the growth of microorganisms and subsequently significantly increased the fruit's shelf life during the storage period (Gol et al., 2013; Vu et al., 2011). Adding lemon EO to chitosan edible coating effectively improved the fresh-keeping performance of the film (Demircan & Özdestan-Ocak, 2021). In addition, Tragacanth gum coating has been shown to improve the quality of tomato fruits, including firmness and appearance. This can have a significant impact on the marketability and product sales of tomatoes (Jahanshahi et al., 2023). Moreover, pectin coating containing orange EO increased the shelf life of orange slices without any adverse effect on sensory characteristics (Radi et al., 2018).

Due to the presence of antimicrobial and polyphenol compounds in citrus EO, such as limonene, beta-pinene, gamma-terpinene, and linalool, it is expected that the use of citrus EO will reduce the number of microorganisms and infections induced by them (Lota et al., 2002), which showed in this experiment alone or combined with MC coating. The hydrophobic nature of EOs will cause them to penetrate the lipids of the cell membrane, release ions, and vital compounds, and eventually cause cell death. Toxic effects on membrane structure and function justify the antimicrobial action of plant EOs and their monoterpene compounds (Jugreet et al., 2020).

Fruit color

Based on the results of the analysis of variance (Table 2), the effect of ST ($P \leq 0.01$) and the effect of EO ($P \leq 0.05$) on the L* color index was significant. However, the effect of edible coating on the L* color index was insignificant. The double and triple interaction effects between the factors also significantly impacted the L* color index. The results showed that the highest L* index was observed in all treatments on day 7. As time passed, this index significantly decreased in all samples. On days 7 and 14, no significant difference between the treatments could be observed. Only on day 21 the 0.5% MC samples without EO (control) had a lower L* index than the other samples. At the same time, there was no significant difference between the other treatments regarding the L* color index (Fig. 4).

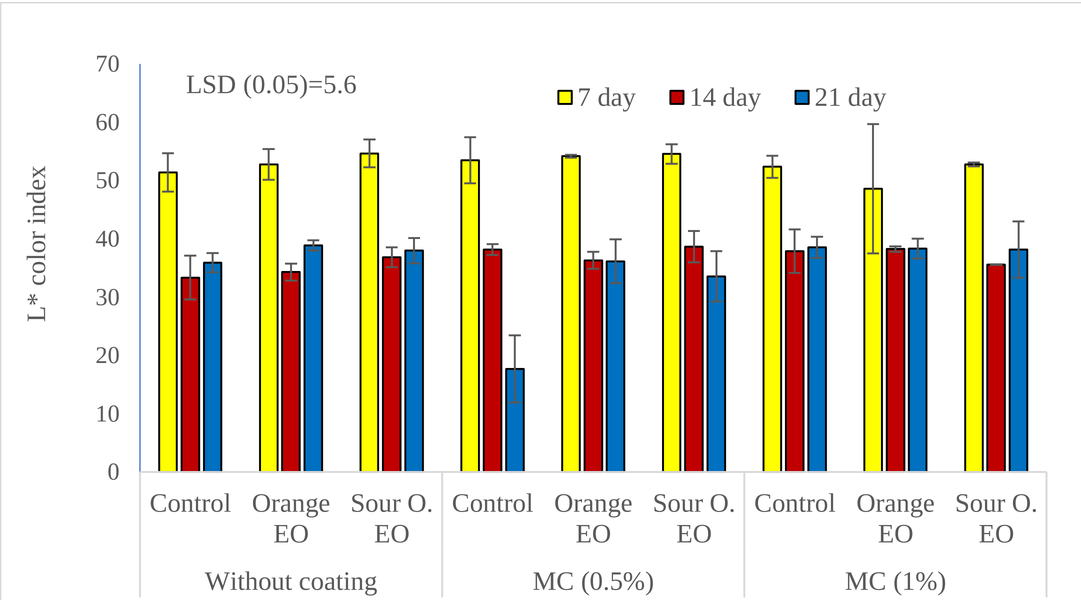


Fig. 4. The effect of MC edible coating and citrus EO on L* color index of tomato fruit during storage at 10 °C with relative humidity ≥ 80%. Error bars represent the standard error of the mean of three replicates.

Table 2 shows significant effects of ST, edible coating ($P \leq 0.01$), and EO ($P \leq 0.05$) on the hue angle. Interaction effects between ST and coating, and ST and EO ($P \leq 0.01$), were also significant, while interactions between coating and EO, and the three factors combined, were insignificant. The highest hue angle occurred on day 7, decreasing significantly by day 14, with no further change by day 21. ST and coating interaction revealed uncoated samples had lower hue angles than MC-coated ones on day 7, but no difference was observed by day 14. On day 21, samples with 0.5% MC had the lowest hue angle (Fig. 5-A). ST and EO interaction showed control samples had higher hue angles than orange and sour orange EO samples on day 7, with no differences between EO types. By days 14 and 21, no differences were observed among the treatments (Fig. 5-B).

The L* index indicates brightness and ranges from 0 to 100, with zero representing black and 100 representing white. An increase in color intensity in red fruits is associated with a decrease in the Hue angle. Additionally, a linear relationship between the reduction of chlorophyll content and the L* color index has been shown in various products (Wrolstad & Smith, 2017). In this experiment, tomato fruits were harvested at the mature green stage and then treated. As time passed, the color intensity of the fruits increased, leading to a decrease in both the Hue angle and the L* index. The results showed that the MC edible coating samples exhibited better color development than the other treatments, particularly the 0.5% concentration.

Weight loss

The analysis of variance revealed significant effects of ST, edible coating, EO, and double and triple interactions among these factors on weight loss ($P \leq 0.01$) (Table 2). Mean comparison results indicated that weight loss increased over time in all treatments, with the highest percentage observed in samples without edible coating or EO treatment. Applying the MC edible coating without EO or EO treatment without coating reduced weight loss. The lowest weight loss percentage was observed in samples treated with 1% MC coating and orange EO, and significant differences were observed between other treatments (Fig. 6-A).

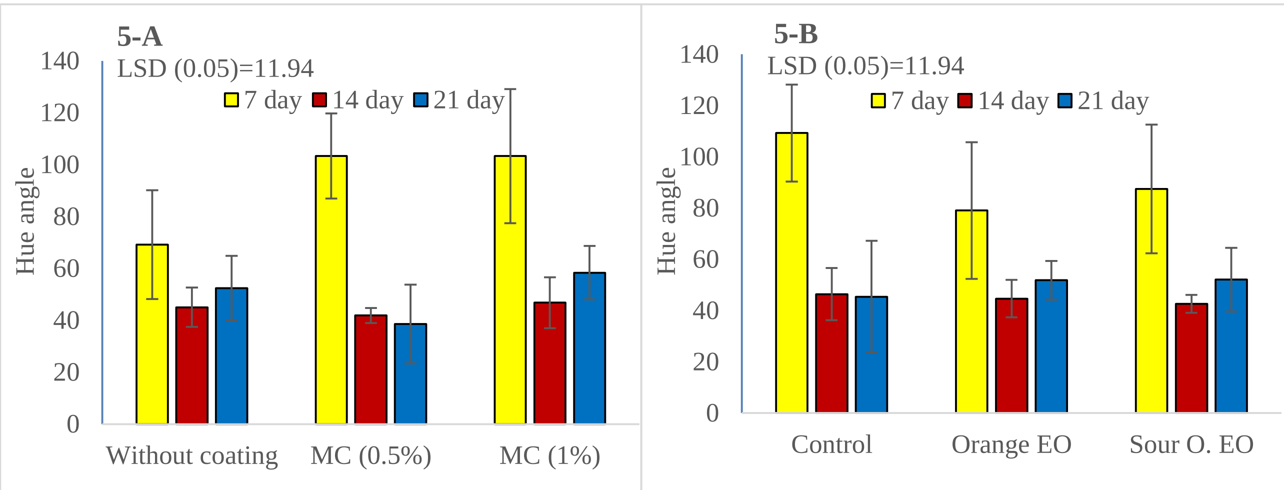


Fig. 5. The effect of MC edible coating (5-A), and citrus EO (5-B) on hue angle of tomato fruit during storage at 10 °C with relative humidity ≥ 80%. Error bars represent the standard error of the mean of three replicates.

After harvesting, fruits remain alive and experience weight loss due to respiratory processes, transpiration, and internal metabolic activities during the postharvest period (Davarynejad et al., 2015). Evaporation and transpiration occur due to differences in water vapor pressure between the intercellular spaces of the fruit tissues and the surrounding atmosphere, as well as increased respiratory conditions (Mostofi et al., 2010). Tomatoes lack thick cuticles and are particularly susceptible to water loss through transpiration, significantly reducing their storability (Khan et al., 2014). Water loss leads to significant changes in cell metabolism, and damage to the cell membrane contributes to weight loss (Mahmoudi et al., 2022).

Plant EOs indirectly control weight loss by delaying the aging process of the fruit (Perumal et al., 2022). Bacteria and fungi that grow on the fruit consume nutrients and accelerate their deterioration, resulting in increased metabolism and weight loss (Yao et al., 2023). In this experiment, EO treatments and MC coating reduced weight loss. Other studies have also reported similar results and the benefits of edible coatings for fruits, such as chitosan (Saleem et al., 2021), gum Arabic xanthan and carrageenan (Wani et al., 2021), pectin and carboxymethyl cellulose (Panahirad et al., 2021), alginate (Duong et al., 2022), and *Aloe vera* gel (Nia et al., 2021). These coatings act as barriers against the diffusion of water vapor and thus slow down weight loss.

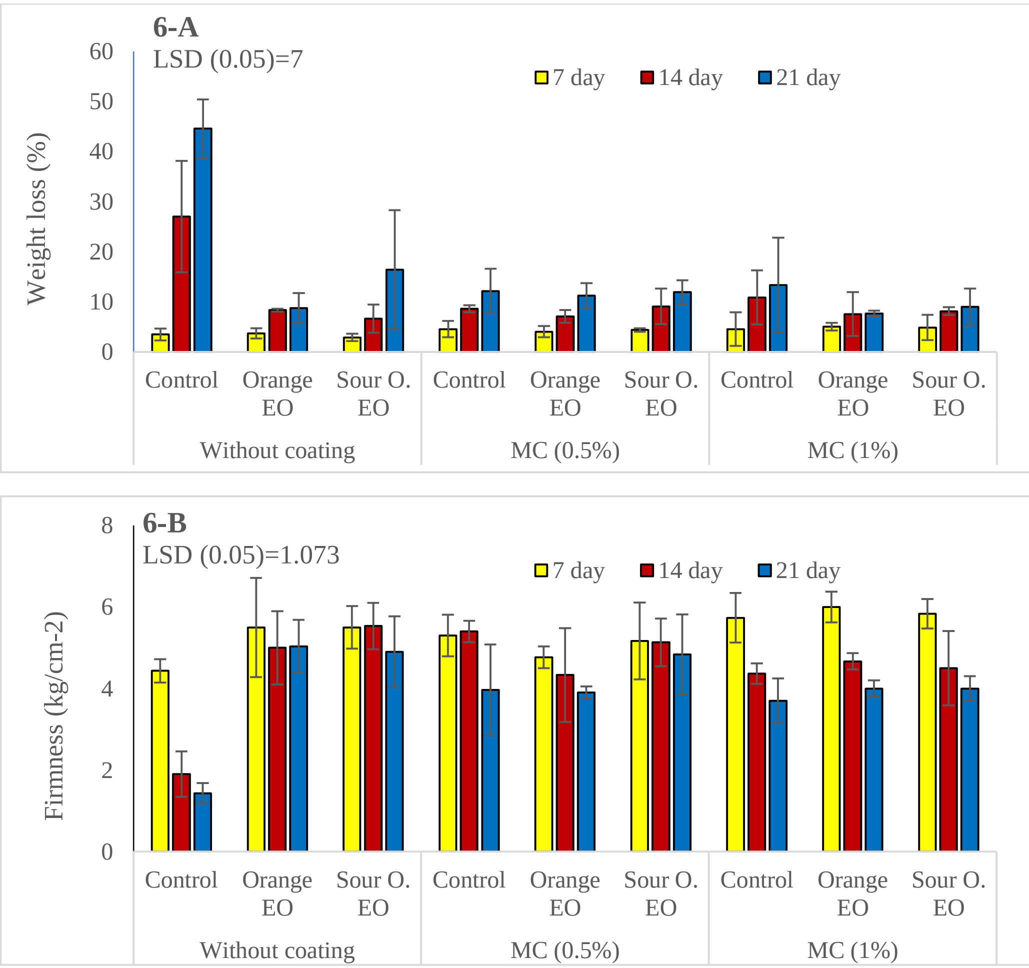


Fig. 6. The effect of MC edible coating and citrus EO on weight loss (6-A), and firmness value of tomato fruit (6-B) during storage at 10 °C with relative humidity ≥ 80%. Error bars represent the standard error of the mean of three replicates.

Tissue firmness

The results of the analysis of variance revealed that the effect of ST ($P \leq 0.01$), the effect of edible coating ($P \leq 0.05$), and the effect of EO ($P \leq 0.01$), as well as the interaction effects between ST and edible coating ($P \leq 0.01$), the interaction between edible coating and EO ($P \leq 0.01$), and the interaction between ST, edible coating, and EO ($P \leq 0.01$) on tissue firmness is significant. However, the interaction effect between ST and EO was non-significant (Table 2).

Based on the test results, the firmness of the tissue decreased significantly with the passage of the test time in all treatments, although the intensity of this decrease varied among the samples. The control samples had the lowest firmness during the study after seven days, indicating the lowest firmness during this test. In contrast, the highest firmness during the experiment was observed in EO-treated samples without coating. Therefore, the application of edible coating treatment (alone or in combination with EO) caused a decrease in firmness compared to the application of EO treatment alone. However, the samples coated with 0.5% MC with sour orange EO had higher firmness than the others (Fig. 6-B).

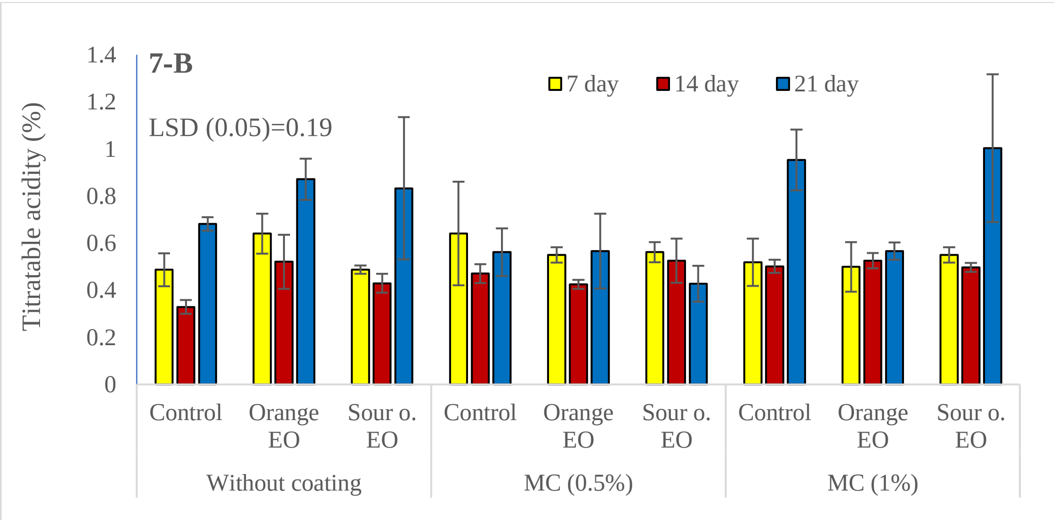
One of the most important characteristics used to determine the quality and storage life of fruits and vegetables is the degree of decrease in firmness during storage (Huang et al., 2018). The characteristics of fruit tissue depend on the cell mass, structure, and composition of cell wall polysaccharides (Moya-León et al., 2019). The softening of fruits is caused by the breakdown of cell wall compounds, especially pectin, by the activity of particular enzymes, including polygalacturonase (Wang et al., 2018). During storage, the increase in the production of free radicals, which is caused by the beginning of the aging process, leads to the destruction of the central vacuole breakdown of proteins, polysaccharides, cell wall structures, and middle membrane, resulting in the breakdown of wall polysaccharides, increased intercellular space, and reduced tissue firmness (Ghosh et al., 2021). On the other hand, EOs inhibited the activity of cell wall-decomposing enzymes to a large extent, reducing the rate of rotting and the activity of microorganisms (Fincheira et al., 2023). This delays the process of ripening and aging, preserving the firmness of the fruit during storage.

In this experiment, MC edible coating was also effective in maintaining tomatoes' proper firmness, but the effect of EO was more evident in this field. The positive impact of edible coatings of cellulose derivatives on the firmness of tomato tissue has been shown already (Das et al., 2022). MC coating had positive effects on the shelf life and firmness of the fruit tissue of avocados. It regulated water vapor, oxygen, and carbon dioxide transfer inside or outside the product and improved its quality and shelf life (Nadim & Ahmadi, 2016). Rajabi et al. (2022) showed that a carboxymethyl cellulose coating with walnut and lemon EO reduced firmness loss in mushrooms, consistent with our findings. Plant gum coatings with clove EO improved strawberry shelf life (Jodhani & Nataraj, 2019), and alginate with black cumin extract slowed weight loss and ripening in guavas (Hasan et al., 2022). In addition, chitosan oligosaccharides treated fruits exhibited significant delays of firmness and weight loss percentage compared to untreated fruits (Nitu et al., 2025).

Total soluble solids

The results showed that the effects of ST, edible coating, and EO, as well as the double and triple interactions between these factors on TSS, were significant ($P \leq 0.01$) (Table 2). The experiment results showed that the lowest amount of TSS was observed in the control samples without edible coating and EO treatment. In these samples, the amount of TSS decreased significantly over time, reaching about 5.0% at the end of the experiment. However, the application of edible coating or EO treatments, alone or in combination, maintained the amount of TSS compared to the control samples throughout the experiment. While statistically significant differences in the amount of TSS were observed between the treatments, all treatments ultimately had higher TSS than the control samples (Fig. 7-A).

The increase in TSS during storage can be attributed to weight loss and decreased water content in the fruit tissue. As the fruit ripens and the respiration rate increases, polysaccharides are broken down and converted into simpler sugars, increasing TSS (Li et al., 2022). The increase in TSS in strawberry fruit during storage observed by (Saeed et al., 2021) aligns with the findings of this study. According to some studies, coating fruits with Arabic gum, which is a natural polysaccharide derived from the exudates of Acacia trees, increased in TSS during storage (Huang et al., 2021; Tiamiyu et al., 2023). Coatings play a crucial role in enhancing and stabilizing the TSS in fruits during storage by reducing moisture loss, slowing respiration, delaying ripening, maintaining acidity and ripening index, and modulating biochemical pathways. These combined effects help preserve the fruit's quality and ensure stable TSS levels over extended storage periods (Huang et al., 2021; Daraghmah & Qubbaj, 2021).



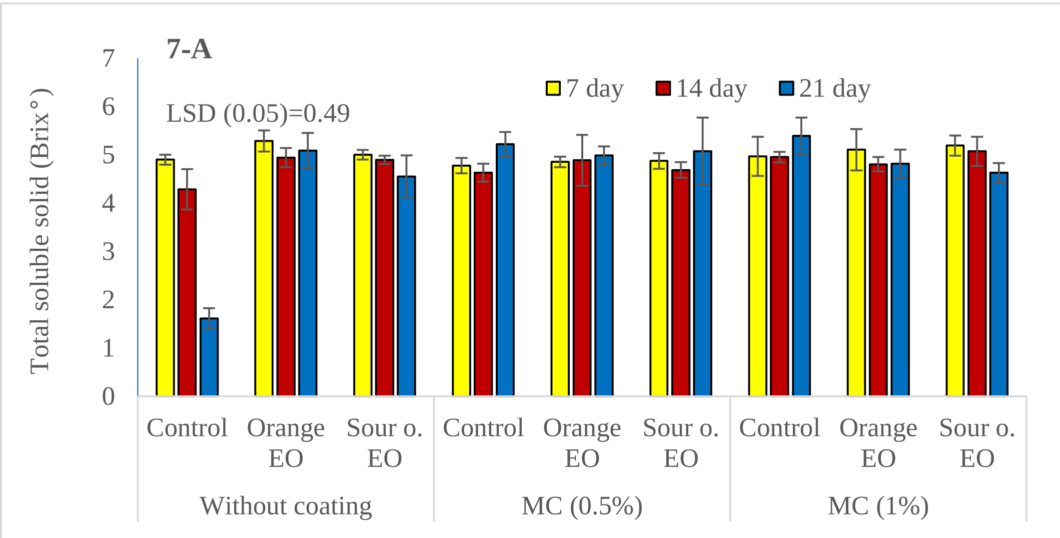


Fig. 7. The effect of MC edible coating and citrus EO on TSS (7-A), and TA percentage (7-B) of tomato fruit during storage at 10 °C with relative humidity ≥ 80%. Error bars represent the standard error of the mean of three replicates.

Titratable acidity

Based on the obtained results, the effect of ST ($P \leq 0.01$), the effect of edible coating ($P \leq 0.05$), the interaction effect between ST and edible coating ($P \leq 0.01$), the interaction between the edible coating and EO ($P \leq 0.01$), and the interaction between ST, edible coating, and EO ($P \leq 0.05$) were found to be significant on TA percentage. However, the effect of EO and the interaction between ST and EO were found to be insignificant (Table 2). The results of mean comparison showed that the trend of TA changes was different based on the type of treatment, but in general, TA in most treatments decreased on the 14th day of the study compared to the 7th day and increased again on the 21st day compared to the 14th day. In the treatment without coating (control, orange, and sour orange EOs) and MC 1% (combined with control and sour orange EO), the highest amount of TA was measured on the 21st day of the study, but in MC coating 0.5% (combined with control, orange, and sour orange EOs) and 1% MC (combined with orange EO) changes in TA were less compared to other treatments (Fig. 7-B).

TA provides valuable information about the taste and flavor of fruits and vegetables. The perceived acidity is a key factor influencing the overall sensory experience and consumer acceptance of the product (Xu et al., 2023). Fruits with an appropriate level of acidity often taste fresher and more flavorful. In general, organic acids act as an energy reserve for fruits during the ripening and aging process, and their consumption increases with metabolism, leading to a decrease in acidity (Rashmi & Negi, 2022). Some studies have reported a relationship between fruit acidity and enzyme activity. The decline in tomato acidity during storage is attributed to metabolic changes caused by consuming organic acids during cellular respiration (Zheng et al., 2022). In tomatoes, citric acid is the primary organic acid used in respiration, and organic acid utilization subsequently decreases TA (Oms-Oliu et al., 2011).

Edible coatings have been found to reduce the respiration rate and delay the reduction process of organic acids, thus maintaining the acidity in fruits (Ehteshami et al., 2022; Sousa et al., 2021). It was shown that gum Arabic coating, which has gas and water vapor barrier properties, resulted in higher TA corresponding with low pH while also maintaining quality, and extending the shelf life of mangoes compared to the control group (Daisy et al., 2020). Additionally, an edible coating made from cassava starch and vegetable oil was found to reduce TA during the storage of tomatoes (Adjouman et al., 2018).

Some research shows that during the ripening of tomato fruit, due to bulky size and the density of the tissues, a hypoxic state is created, which leads to a decrease in respiration and an increase in fermentation in the fruit tissues. In this case, the consumption of organic acids decreases, while some acids are also produced due to fermentation, which may be the reason for the increase in TA observed in this experiment at the end of the ripening stage. The greatest increase in acidity was observed in the control fruits and those treated with 1% methyl cellulose. Perhaps the thicker fruit coating in this case and the greater density of the control fruit tissue created more suitable conditions for the hypoxic phenomenon, which was followed by an increase in TA (Xiao et al., 2024).

CONCLUSION

In conclusion, this study demonstrated the significant potential of MC edible coating and citrus EO in enhancing disease control and preserving the postharvest quality of tomato fruit. Applying MC proved effective in reducing fruit weight loss, while both edible coating and EO treatments contributed to maintaining the overall quality of the fruit. Notably, the combination of these treatments outperformed individual applications. Highly perishable tomatoes face rapid deterioration postharvest. As a novel strategy, incorporating bioactive compounds such as EOs into edible coatings shows promise in extending shelf life by addressing issues like moisture loss and metabolism and reducing microbial load. In addition, this research contributes valuable insights into postharvest management in the fresh-eating and processing industries, offering practical implications for sustainable and effective preservation methods for tomato fruit. This approach offers a sustainable and effective alternative to traditional chemical treatments while providing consumers with a healthier and more flavorful product. Further research and practical applications of these findings can contribute to developing sustainable and safe postharvest management practices in the tomato industry.

Conflict of interest

The authors state that they have no competing financial interests related to the publication of this work.

Acknowledgment

The authors sincerely appreciate Shahed University for supporting this research.

REFERENCES

Adjouman, Y.D., Nindjin, C., Kouassi, K.N., Tetchi, F.A., N'Guessan, G.A. & Sindic, M. (2018). Effect of edible coating based on improved cassava starch on post-harvest quality of fresh tomatoes (*Solanum lycopersicum* L.). *International Journal of Nutritional Science and Food Technology*, *4*(1), 1-10.

Alegbeleye, O., Odeyemi, O.A., Strateva, M. & Stratev, D. (2022). Microbial spoilage of vegetables, fruits and cereals. *Applied Food Research*, *2*(1), 100122. https://doi.org/10.1016/j.afres.2022.100122

Angane, M., Swift, S., Huang, K., Butts, C.A. & Quek, S.Y. (2022). Essential oils and their major components: an updated review on antimicrobial activities, mechanism of action and their potential application in the food industry. *Foods*, 11(3), 464. https://doi.org/10.3390/foods11030464

Barbosa, C.H., Andrade, M.A., Vilarinho, F., Fernando, A.L. & Silva, A.S. (2021). Active edible packaging. *Encyclopedia*, *1*(2), 360-370. https://doi.org/10.21273/HORTSCI.37.3.559

Barzegar, T., Fateh, M. & Razavi, F. (2018). Enhancement of postharvest sensory quality and antioxidant capacity of sweet pepper fruits by foliar applying calcium lactate and ascorbic acid. *Scientia Horticulturae*, *241*, 293-303. https://doi.org/10.1016/j.scienta.2018.07.011

Butnariu, M. (2021). Plants as source of essential oils and perfumery applications. *Bioprospecting of Plant Biodiversity for Industrial Molecules*, 261-292. https://doi.org/10.1002/9781119718017.ch13

Chanthaphon, S., Chanthachum, S. & Hongpattarakere, T. (2018). Antimicrobial activities of essential oils and crude extract from tropical citrus spp. against food-related microorganism. Songklanakarin *Journal of Science and Technology*, *30*(1), 125-131.

Daisy, L.L., Nduko, J.M., Joseph, W.M. & Richard, S.M. (2020). Effect of edible gum Arabic coating on the shelf life and quality of mangoes (*Mangifera indica*) during storage. *Journal of Food Science and Technology*, *57*, 79-85. https://doi.org/10.1007/s13197-019-04032-w

Daraghmah, F. S., & Qubbaj, T. (2021). Impact of gum arabic and cactus mucilage as potential coating substances combined with calcium chloride treatment on tomato (*Solanum lycopersicum* L.) fruit quality attributes under ambient storage conditions. *Canadian Journal of Plant Science*, *102*(2), 375-384. https://doi.org/10.1139/CJPS-2021-0164

Das, S.K., Vishakha, K., Das, S., Chakraborty, D. & Ganguli, A. (2022). Carboxymethyl cellulose and cardamom oil in a nanoemulsion edible coating inhibit the growth of foodborne pathogens and extend the shelf life of tomatoes. *Biocatalysis and Agricultural Biotechnology*, *42*, 102369. https://doi.org/10.1016/j.bcab.2022.102369

Davarynejad, G.H., Arefkhani, S., Azizi, M. & Zarei, M. (2015). Evaluation of salicylic acid and calcium chloride effect on shelf life, quality properties and antioxidant activity of peach fruit cv. Amesden after harvest. *Journal of Horticultural Science*, *28*(4), 464-478. https://doi.org/10.22067/jhorts4.v0i0.45083

Demircan, B. & Özdestan-Ocak, Ö. (2021). Effects of lemon essential oil and ethyl lauroyl arginate on the physico-chemical and mechanical properties of chitosan films for mackerel fillet coating application. *Journal of Food Measurement and Characterization*, *15*, 1499-1508. https://doi.org/10.1007/s11694-020-00745-1

Duong, N.T.C., Uthairatanakij, A., Laohakunjit, N., Jitareerat, P. & Kaisangsri, N. (2022). An innovative single step of cross-linked alginate-based edible coating for maintaining postharvest quality and reducing chilling injury in rose apple cv. 'Tabtimchan' (*Syzygium samarangenese*). *Scientia Horticulturae*, 292, 110648. https://doi.org/10.1016/j.scienta.2021.110648

Ehteshami, S., Dastjerdi, A.M., Ramezanian, A., Etemadipoor, R., Abdollahi, F., Salari, M. & Shamili, M. (2022). Effects of edible alginate coating enriched with organic acids on quality of mango fruit during storage. *Journal of Food Measurement and Characterization*, *16*, 400-409. https://doi.org/10.1007/s11694-021-01166-4

Elik, A., Yanik, D.K., Istanbullu, Y., Guzelsoy, N.A., Yavuz, A. & Gogus, F. (2019). Strategies to reduce post-harvest losses for fruits and vegetables. *Strategies*, *5*(3), 29-39.

Fincheira, P., Jofré, I., Espinoza, J., Levío-Raimán, M., Tortella, G., Oliveira, H.C., Diez, M.C., Quiroz, A. & Rubilar, O. (2023). The efficient activity of plant essential oils for inhibiting Botrytis cinerea and Penicillium expansum: Mechanistic insights into antifungal activity. *Microbiological Research*, 277, 127486. DOI: 10.1016/j.micres.2023.127486

Ghosh, A., Saha, I., Debnath, S.C., Hasanuzzaman, M. & Adak, M.K. (2021). Chitosan and putrescine modulate reactive oxygen species metabolism and physiological responses during chili fruit ripening. *Plant Physiology and Biochemistry*, *163*, 55-67. https://doi.org/10.1016/j.plaphy.2021.03.026

Gol, N.B., Patel, P.R. & Rao, T.V.R. (2013). Improvement of quality and shelf-life of strawberries with edible coatings enriched with chitosan. *Postharvest Biology and Technology*, *85*, 185-195. https://doi.org/10.1016/j.postharvbio.2013.06.008

González-Mas, M.C., Rambla, J.L., López-Gresa, M.P., Blázquez, M.A. & Granell, A. (2019). Volatile compounds in citrus essential oils: A comprehensive review. *Frontiers in Plant Science*, 10: 12. https://doi.org/10.3389/fpls.2019.00012

Hasan, K., Islam, R., Hasan, M., Sarker, S.H. & Biswas, M.H. (2022). Effect of alginate edible coatings enriched with black cumin extract for improving postharvest quality characteristics of guava (*Psidium guajava* L.) fruit. *Food and Bioprocess Technology*, *15*(9), 2050-2064. https://doi.org/10.1007/s11947-022-02869-2

Huang, Q., Wan, C., Zhang, Y., Chen, C. & Chen, J. (2021). Gum arabic edible coating reduces postharvest decay and alleviates nutritional quality deterioration of ponkan fruit during cold storage. *Frontiers in Nutrition*, *8*, 717596. https://doi.org/10.3389/fnut.2021.717596

Huang, Y., Lu, R. & Chen, K. (2018). Prediction of firmness parameters of tomatoes by portable visible and near-infrared spectroscopy. *Journal of Food Engineering*, *222*, 185-198. https://doi.org/10.1016/j.jfoodeng.2017.11.030

Iñiguez-Moreno, M., Santiesteban-Romero, B., Flores-Contreras, E.A., Scott-Ayala, S., Araújo, R.G., Iqbal, H., Melchor-Martínez, E.M. & Parra-Saldívar, R. (2024). Sustainable solutions for postharvest berry protection: natural edible coatings. *Food and Bioprocess Technology*, https://doi.org/10.1007/s11947-023-03301-z.

Jahanshahi, B., Jafari, A., & Gholamnezhad, J. (2023). Effect of edible tragacanth coating on fruit quality of tomato cv. Falkato. *Journal of Horticulture and Postharvest Research*, *6*(1), 43-54. https://doi.org/10.22077/jhpr.2022.5478.1282

Jiang, T., Jahangir, M.M., Jiang, Z., Lu, X. & Ying, T. (2010). Influence of UV-C treatment on antioxidant capacity, antioxidant enzyme activity and texture of postharvest shiitake (*Lentinus edodes*) mushrooms during storage. *Postharvest Biology and Technology*, *56*(3), 209-215. https://doi.org/10.1016/j.postharvbio.2010.01.011

Jodhani, K.A. & Nataraj, M. (2019). Edible coatings from plant-derived gums and clove essential oil improve postharvest strawberry (*Fragaria× ananassa*) shelf life and quality. *Environmental and Experimental Biology*, *17,* 123–135. https://doi.org/10.22364/eeb.17.13

Jugreet, B.S., Suroowan, S., Rengasamy, R.R.K. & Mahomoodally, M.F. (2020). Chemistry, bioactivities, mode of action and industrial applications of essential oils. *Trends in Food Science and Technology*, *101,* 89-105. https://doi.org/10.1016/j.tifs.2020.04.025

Khademi, O., Zamani, Z., Poor Ahmadi, E. & Kalantari, S. (2013). Effect of UV-C radiation on postharvest physiology of persimmon fruit (*Diospyros kaki* Thunb.) cv. 'Karaj' during storage at cold temperature. *International Food Research Journal*, *20*(1), 247-253.

Khan, Z.U., Aisikaer, G., Khan, R.U., Bu, J., Jiang, Z., Ni, Z. & Ying, T. (2014). Effects of composite chemical pretreatment on maintaining quality in button mushrooms (*Agaricus bisporus*) during postharvest storage. *Postharvest Biology and Technology*, *95,* 36-41. https://doi.org/10.1016/j.postharvbio.2014.04.001

Kocira, A., Kozłowicz, K., Panasiewicz, K., Staniak, M., Szpunar-Krok, E. & Hortyńska, P. (2021). Polysaccharides as edible films and coatings: Characteristics and influence on fruit and vegetable quality—A review. *Agronomy*, *11*(5), 813. https://doi.org/10.3390/agronomy11050813

Li, D., Deng, L., Dai, T., Chen, M., Liang, R., Liu, W., Liu, C., Chen, J. & Sun, J. (2022). Ripening induced degradation of pectin and cellulose affects the far infrared drying kinetics of mangoes. *Carbohydrate Polymers*, *291,* 119582. https://doi.org/10.1016/j.carbpol.2022.119582

Lota, M.-L., de Rocca Serra, D., Tomi, F., Jacquemond, C. & Casanova, J. (2002). Volatile components of peel and leaf oils of lemon and lime species. *Journal of Agricultural and Food Chemistry*, *50*(4), 796-805. https://doi.org/10.1021/jf010924l

Mahmoudi, R., Razavi, F., Rabiei, V., Gohari, G. & Palou, L. (2022). Application of Glycine betaine coated chitosan nanoparticles alleviate chilling injury and maintain quality of plum (*Prunus domestica* L.) fruit. *International Journal of Biological Macromolecules*, *207,* 965-977. https://doi.org/10.1016/j.ijbiomac.2022.03.167

Mesías, F.J., Martín, A. & Hernández, A. (2021). Consumers' growing appetite for natural foods: Perceptions towards the use of natural preservatives in fresh fruit. *Food Research International*, *150,* 110749. https://doi.org/10.1016/j.foodres.2021.110749

Moradinezhad, F. & Firdous, N. (2025). Recent advances in application of edible coatings for temperate fresh/fresh-cut fruits: a review. *Journal of Horticulture and Postharvest Research*, *8*(2), 151-176. https://doi.org/10.22077/jhpr.2024.8163.1425

Mostofi, Y., Zadeh, A.M., Jomeh, Z.E., Nikkhah, M.J. & Ardakani, M.D. (2010). Evaluation of modified atmospher packaging (MAP) to control gray mould in 'Shahroodi' table grapes. Iranian *Journal of Horticultural Science*, *41*(2), 163-172. https://doi.org/10.3389/fpls.2019.00615

Moya-León, M.A., Mattus-Araya, E. & Herrera, R. (2019). Molecular events occurring during softening of strawberry fruit. *Frontiers in Plant Science*, *10,* 615. https://doi.org/10.3389/fpls.2019.00615

Nadim, Z. & Ahmadi, E. (2016). Rheological properties of strawberry fruit coating with methylcellulose. *Journal of Agricultural Machinery*, *6*(1), 153-162. https://doi.org/10.22067/jam.v6i1.31349

Ni, Z.-J., Wang, X., Shen, Y., Thakur, K., Han, J., Zhang, J.-G., Hu, F. & Wei, Z.-J. (2021). Recent updates on the chemistry, bioactivities, mode of action, and industrial applications of plant essential oils. *Trends in Food Science and Technology*, *110,* 78-89. https://doi.org/10.1016/j.tifs.2021.01.070

Nia, A.E., Taghipour, S. & Siahmansour, S. (2021). Pre-harvest application of chitosan and postharvest Aloe vera gel coating enhances quality of table grape (*Vitis vinifera* L. cv.'Yaghouti') during postharvest period. *Food Chemistry*, *347,* 129012. https://doi.org/10.1016/j.foodchem.2021.129012

Nitu, N., Ullah, M. S., Howlader, P., Mehedi, M. N., Meem, H., & Bose, S. (2025). Chitosan oligosaccharides maintained postharvest quality and increased shelf life of mango. *Journal of Horticulture and Postharvest Research*, *8*(1), 43-66. https://doi.org/10.22077/jhpr.2024.7888.1395

Oms-Oliu, G., Hertog, M., Van de Poel, B., Ampofo-Asiama, J., Geeraerd, A.H. & Nicolai, B.M. (2011). Metabolic characterization of tomato fruit during preharvest development, ripening, and postharvest shelf-life. *Postharvest Biology and Technology*, *62*(1), 7-16. https://doi.org/10.1016/j.postharvbio.2011.04.010

Oraee, A., Selahvarzi, Y., Ghazimoghadam, M., Abedy, B., & Sabokkhiz, M. A. (2025). Enhancing decay resistance and maintaining quality of stored apples (*Malus domestica* 'Golden Delicious') through essential oil-enriched edible coatings. *Journal of Horticulture and Postharvest Research*, *8*(1), 27-42. https://doi.org/10.22077/jhpr.2024.7686.1385

Panahirad, S., Dadpour, M., Peighambardoust, S.H., Soltanzadeh, M., Gullón, B., Alirezalu, K. & Lorenzo, J.M. (2021). Applications of carboxymethyl cellulose-and pectin-based active edible coatings in preservation of fruits and vegetables: A review. *Trends in Food Science and Technology*, *110*, 663-673. https://doi.org/10.1016/j.tifs.2021.02.025

Park, M.-H., Sangwanangkul, P. & Choi, J.W. (2018). Reduced chilling injury and delayed fruit ripening in tomatoes with modified atmosphere and humidity packaging. *Scientia Horticulturae*, *231*, 66-72. https://doi.org/10.1016/j.scienta.2017.12.021

Peralta-Ruiz, Y., Tovar, C.D.G., Sinning-Mangonez, A., Coronell, E.A., Marino, M.F. & Chaves-Lopez, C. (2020). Reduction of postharvest quality loss and microbiological decay of tomato "Chonto" (*Solanum lycopersicum* L.) using chitosan-e essential oil-based edible coatings under low-temperature storage. *Polymers*, *12*(8), 1822. https://doi.org/10.3390/polym12081822

Perez-Vazquez, A., Barciela, P., Carpena, M. & Prieto, M.A. (2023). Edible coatings as a natural packaging system to improve fruit and vegetable shelf life and quality. *Foods*, *12*(19), 3570. https://doi.org/10.3390/foods12193570

Perumal, A.B., Huang, L., Nambiar, R.B., He, Y., Li, X. & Sellamuthu, P.S. (2022). Application of essential oils in packaging films for the preservation of fruits and vegetables: A review. *Food Chemistry*, *375*, 131810. https://doi.org/10.1016/j.foodchem.2021.131810

Radi, M., Akhavan-Darabi, S., Akhavan, H.R. & Amiri, S. (2018). The use of orange peel essential oil microemulsion and nanoemulsion in pectin-based coating to extend the shelf life of fresh-cut orange. *Journal of Food Processing and Preservation*, *42*(2), e13441. https://doi.org/10.1111/jfpp.13441

Raguso, R.A. (2020) Handbook of Essential Oils. CRC Press.

Rahman, K.R., Ramdhani, S., Sanyoto, V.G. & Nawareza, Z. (2024). Smart packaging innovation for food: enhancing shelf life and quality of perishable goods. *Asean Journal for Science and Engineering in Materials*, *3*(2),133-140. https://doi.org/10.1016/j.focha.2024.100769

Rajabi, S., Bahrami, S. & Abdolahian-Noghabi, M. (2022). The effect of active packaging based on carboxymethyl cellulose contains walnut and lemon peels essential oils on the shelf life of mushroom. *Journal of Food Science and Technology* (Iran), *19*(130), 155-169.

Rashmi, H.B. & Negi, P.S. (2022). Advances in food chemistry: Food components, processing and preservation, *Springer*, pp. 439-470.

Robledo, N., Vera, P., López, L., Yazdani-Pedram, M., Tapia, C. & Abugoch, L. (2018). Thymol nanoemulsions incorporated in quinoa protein/chitosan edible films; antifungal effect in cherry tomatoes. *Food Chemistry*, *246*, 211-219. https://doi.org/10.1016/j.foodchem.2017.11.032

Saeed, M., Azam, M., Saeed, F., Arshad, U., Afzaal, M., Bader Ul Ain, H., Ashraf, J. & Nasir, Z. (2021). Development of antifungal edible coating for strawberry using fruit waste. *Journal of Food Processing and Preservation*, *45*(11), e15956. https://doi.org/10.1111/jfpp.15956

Saleem, M.S., Anjum, M.A., Naz, S., Ali, S., Hussain, S., Azam, M., Sardar, H., Khaliq, G., Canan, İ. & Ejaz, S. (2021). Incorporation of ascorbic acid in chitosan-based edible coating improves postharvest quality and storability of strawberry fruits. *International Journal of Biological Macromolecules*, *189*, 160-169. https://doi.org/10.1016/j.ijbiomac.2021.08.051

Satari, B. & Karimi, K. (2018). Citrus processing wastes: Environmental impacts, recent advances, and future perspectives in total valorization. *Resources, Conservation and Recycling*, *129*, 153-167. https://doi.org/10.1016/j.resconrec.2017.10.032

Simas, D.L.R., de Amorim, S.H.B.M., Goulart, F.R.V., Alviano, C.S., Alviano, D.S. & da Silva, A.J.R. (2017). Citrus species essential oils and their components can inhibit or stimulate fungal growth in fruit. *Industrial Crops and Products*, *98*, 108-115.

https://doi.org/10.1016/j.indcrop.2017.01.026
Sousa, F.F., Junior, J.S.P., Oliveira, K.T.E.F., Rodrigues, E.C.N., Andrade, J.P. & Mattiuz, B.-H. (2021). Conservation of 'Palmer'mango with an edible coating of hydroxypropyl methylcellulose and beeswax. *Food Chemistry, 346*, 128925. https://doi.org/10.1016/j.foodchem.2020.128925
Suhag, R., Kumar, N., Petkoska, A.T. & Upadhyay, A. (2020). Film formation and deposition methods of edible coating on food products: A review. *Food Research International*, *136*, 109582. https://doi.org/10.1016/j.foodres.2020.109582
Thole, V., Vain, P., Yang, R.Y., Almeida Barros da Silva, J., Enfissi, E.M.A., Nogueira, M., Price, E.J., Alseekh, S., Fernie, A.R. & Fraser, P.D. (2020). Analysis of tomato post-harvest Pproperties: fruit color, shelf life, and fungal susceptibility. *Current Protocols in Plant Biology*, *5*(2), e20108. https://doi.org/10.1002/cppb.20108
Tiamiyu, Q.O., Adebayo, S.E. & Yusuf, A.A. (2023). Gum arabic edible coating and its application in preservation of fresh fruits and vegetables: A review. *Food Chemistry Advances*, *2*, 100251. https://doi.org/10.1016/j.focha.2023.100251
Tzortzakis, N., Xylia, P. & Chrysargyris, A. (2019). Sage essential oil improves the effectiveness of Aloe vera gel on postharvest quality of tomato fruit. *Agronomy*, *9*(10), 635. https://doi.org/10.3390/agronomy9100635
Vu, K.D., Hollingsworth, R.G., Leroux, E., Salmieri, S. & Lacroix, M. (2011). Development of edible bioactive coating based on modified chitosan for increasing the shelf life of strawberries. *Food Research International*, *44*(1), 198-203. https://doi.org/10.1016/j.foodres.2010.10.037
Wang, D., Yeats, T.H., Uluisik, S., Rose, J.K.C. & Seymour, G.B. (2018). Fruit softening: revisiting the role of pectin. *Trends in Plant Science*, 23(4): 302-310. DOI: 10.1016/j.tplants.2018.01.006
Wani, S.M., Gull, A., Ahad, T., Malik, A.R., Ganaie, T.A., Masoodi, F.A. & Gani, A. (2021). Effect of gum Arabic, xanthan and carrageenan coatings containing antimicrobial agent on postharvest quality of strawberry: assessing the physicochemical, enzyme activity and bioactive properties. *International Journal of Biological Macromolecules*, *183*, 2100-2108. https://doi.org/10.1016/j.ijbiomac.2021.06.008
Won, J.S., Lee, S.J., Park, H.H., Song, K.B. & Min, S.C. (2018). Edible coating using a chitosan-based colloid incorporating grapefruit seed extract for cherry tomato safety and preservation. *Journal of Food Science*, *83*(1), 138-146. https://doi.org/10.1111/1750-3841.14002
Wrolstad, R.E. & Smith, D.E. (2017). Color analysis. Food Analysis, pp: 545-555. Springer.
Xiao, H., Verboven, P., Tong, S., Pedersen, O. & Nicolaï, B. (2024). Hypoxia in tomato (*Solanum lycopersicum*) fruit during ripening: Biophysical elucidation by a 3D reaction–diffusion model. *Plant Physiology*, *195*(3), 1893–1905. https://doi.org/10.1093/plphys/kiae174.
Xu, L., Zang, E., Sun, S. & Li, M. (2023). Main flavor compounds and molecular regulation mechanisms in fruits and vegetables. *Critical Rreviews in Food Science and Nnutrition*, *63*(33), 11859-11879. DOI: 10.1080/10408398.2022.2097195
Yao, J., Chen, W. & Fan, K. (2023). Recent advances in light irradiation for improving the preservation of fruits and vegetables: A review. *Food Bioscience*, *26*, 103206. https://doi.org/10.1016/j.fbio.2023.103206
Zhang, X., Zhang, X., Liu, X., Du, M. & Tian, Y. (2019). Effect of polysaccharide derived from Osmunda japonica Thunb-incorporated carboxymethyl cellulose coatings on preservation of tomatoes. *Journal of Food Processing and Preservation*, *43*(12), e14239. https://doi.org/10.1111/jfpp.14239
Zheng, Y., Yang, Z., Wei, T. & Zhao, H. (2022). Response of tomato sugar and acid metabolism and fruit quality under different high temperature and relative humidity conditions. *Phyton-International Journal of Experimental Botany*, *91*(9), 2033-2054. https://doi.org/10.32604/phyton.2022.019468