POSTHARVEST TECHNOLOGY
Article

https://doi.org/10.1590/1678-4499.20210221

Impacts of edible coatings enriched with laurel essential oil on the storage life of strawberry 'Camarosa' fruits

İbrahim Kahramanoğlu[1,*], Nadire Pelin Bahadırlı[2], Volkan Okatan[3], Chunpeng (Craig) Wan[4]

1. European University of Lefke – Faculty of Agricultural Sciences and Technologies – Department of Horticulture – Gemikonagi – Northern Cyprus, Turkey.
2. Hatay Mustafa Kemal University – Faculty of Agriculture – Department of Field Crops – Hatay, Turkey.
3. Eskişehir Osmangazi University – Faculty of Agriculture – Department of Horticulture – Eskişehir, Turkey.
4. Jiangxi Agricultural University – College of Agronomy – Jiangxi Key Laboratory for Postharvest Technology and Nondestructive Testing of Fruits & Vegetables – Nanchang, China.

Received: Jul. 25, 2021 | **Accepted:** Jan. 1, 2022
Section Editor: Juliana Sanches
***Corresponding author:** ibrahimcy84@yahoo.com
How to cite: Kahramanoğlu, İ., Bahadırlı, N. P., Okatan, V. and Wan, C. (2022) Impacts of edible coatings enriched with laurel essential oil on the storage life of strawberry 'Camarosa' fruits. Bragantia, 81, e1922. https://doi.org/10.1590/1678-4499.0210221

ABSTRACT: The current research was carried out to test the effects of edible coatings (EC) enriched with laurel essential oil (EC+LEO) on the storability of strawberry 'Camarosa' fruits. Freshly harvested strawberry fruits were randomly separated into three groups and each group was treated with a different treatment, including EC, EC+LEO and control. Fruits were stored at 4.0 ± 1.0 °C and a relative humidity of 90–95% for 15 days. Results suggested that both EC and EC+LEO have positive effects of the quality parameters of strawberry fruits and help to improve the storage duration of the fruits. After 15 days of storage, the average weight loss of the control fruits reached to 12.44%, but was kept at 9.06% and 7.13% at the EC and EC+LEO treated fruits, respectively. Both the EC and EC+LEO treatments were found to have positive impact on the prevention of disease severity and chemical spoilage and lowering respiration rate of the fruits. The loss in the fruit firmness, soluble solids concentration, ascorbic acid content and titratable acidity of the fruits were also found to delay in the coated fruits. The EC+LEO treatment was found to have better performance than the EC treatment. Overall results recommended that the edible coatings enriched with laurel essential oil improve the storability of strawberry fruits and have possibility to be used in postharvest industry.
Key words: edible coatings, laurel essential oil, disease severity, fruit storability, weight loss.

INTRODUCTION

Strawberry (*Fragaria* × *ananassa* Duch.) fruits are highly preferred by consumers because of their unique flavors and their high phytochemical content. The phytochemicals and phenolic compounds in any fruits and also in strawberries provide antioxidant ability, anticarcinogenic and anti-inflammatory properties to the fruits which improves their attractiveness by the consumers (Oszmiański and Wojdyło 2009). Strawberry fruits are nonclimacteric and they have to be harvested at the full maturity (Cordenunsi et al. 2005; Kader 1991). However, full mature strawberry fruits are very sensitive to storage conditions due to their physical properties and high respiration rates, and their storage life is very short (2–5 days). Strawberry fruits are also susceptible to pathogen infections (mainly caused by gray mold: *Botrytis cinerea*) and mechanical injuries (Caleb et al. 2016).

Immediate cooling and storage at low temperatures (0–4 °C) are recommended for the storage of strawberry fruits (Watkins and Nock 2012). Low temperature is helpful for both reducing respiration rate and pathogen development. Another important treatment for the prevention of pathogen development is the use of agrochemicals. However, the acceptability of agrochemicals, has been decreasing in recent years with the increasing consumer awareness, and scientifically confirmed negative effects of misuse and excessive use of agrochemical on human health and ecosystem (Koch et al. 2017). There are several other ways for reducing the respiration rate and increasing the storability of fruits. Some well-known methods are: modified atmosphere packaging, edible films and edible coatings (Khodaei et al. 2021; Pavinatto et al. 2020; Quintana et al. 2021; Ventura-Aguilar et al. 2018). However, the acceptability of plastic materials has been decreasing due to their high persistence in nature, while the public interest is increasing for the edible films and coatings (Ferreira et al. 2016). The most important advantage of these edible materials is their biodegradability and environmental-friendly characteristics (Nor and Ding 2020). Thus, scientific studies have begun to focus more on the testing of edible films and coatings derived mostly from proteins, polysaccharides, lipids and secondary metabolites (essential oils). Moreover, several studies recommended that those edible films and coatings have a very important role in fruit storage (Chen et al. 2019; Kahramanoğlu, 2020; Riva et al. 2020; Wan et al. 2021).

Edible film/coating and essential oil applications, separately, help to preserve the postharvest quality of fruits mostly by reducing respiration rate of fruits and delaying senescence (Kahramanoğlu 2019; Riva et al. 2020). Polysaccharides obtained from plant or animals are complex carbohydrates with glycosidic bonds (Thakur and Thakur 2015). Polysaccharide-based edible films/coatings provide a good barrier against oxygen and carbon dioxide, but their ability to control water vapor is low due to their hydrophilic properties (Rhim et al. 2013). Starch is one of the most used edible film materials among the vegetable-based polysaccharides. The efficacy of starch as edible coating is mostly improved by incorporating with plasticizers like glycerol and sorbitol, which has high hydrophilic properties and low flexibility (Müller et al. 2008; Ortega-Toro et al. 2015).

Essential oils not only have an impact on the reduction of respiration rate, but also to reduce postharvest spoilage caused by fungi. In such study, De Corato et al. (2010) reported that laurel (*Laurus nobilis*) essential oil has moderate to high antifungal activity, which inhibits the mycelial growth of *Botrytis cinerea* and *Penicillium digitatum*. However, there are very few studies (i.e., Hashemi et al. 2021; Praseptiangga et al. 2017) about the combined effects essential oils and edible coatings, while we reached no records for laurel essential oil. Therefore, incorporation of starch-based edible coatings with laurel essential oil may provide better performance in postharvest storage. In the present study, the effects of edible coating (made with corn starch and glycerol) and edible coatings enriched with laurel essential oil on the postharvest preservation quality of strawberry fruits were investigated.

MATERIALS AND METHODS

Materials

Strawberry 'Camarosa' fruits were used in this study. Strawberry fruits at eating maturity were hand collected on March 12, 2021 from a commercial strawberry business located in the village of Yeşilırmak, northern part of Cyprus. Harvesting was done during the morning hours and the fruits were immediately transferred to the laboratory of the Research and Application Farm of the European University of Lefke, within 30 min. In this study, corn starch was purchased from regional markets and the glycerol (~87% purity, belonging to the Merck Chemical Company, Germany) was obtained from a local pharmacy.

Plant material and extraction of essential oil

Fresh leaves of laurel (*L. nobilis*) plants were collected from the flora of Hatay. Fresh leaves were air-dried at 35 °C at the drying oven. Then, 25 g of dried laurel leaves were hydrodistilled with three replicates for three hours with glass Clevenger-type apparatus. The essential oil ratio was calculated as v/w percentage and the essential oil yield was found as 2.5%. The obtained essential oils were stored at +4 °C until the analysis. Laurel essential oil produced from the same methods was then used in the postharvest studies.

Determination of essential oil compounds

Gas chromatography-mass spectrometry (GC-MS) method with Thermo Scientific ISQ Single Quadrupole device was used for analyzing the compounds of essential oils. The method described by Bahadırlı et al. (2020) was followed for the determination of the compounds of essential oils. The individual constituents were identified by comparison of their retention indices with those of known compounds retrieved from the literature.

Experimental Studies

This study was established with three treatments and three replications according to the completely randomized design. Each replication was composed from six preselected healthy fruits. Experiments were planned to continue for 15 days and the quality parameters of the fruits were measured within a 3-day interval. Accordingly, 90 fruits were allocated for each treatment and 18 fruits (three replications) were analyzed at each measurement point. The treatments of the present study are as follows: dipping in pure water (control), edible coating (EC) and edible coating enriched with laurel essential oil (EC+LEO). The method of edible coating preparation was modified from several previous studies (Casariego et al. 2008; Lintang et al. 2021; Sapper and Chiralt 2018). The method used is as follows: corn starch (2% w/v) (Ribeiro et al. 2007; Sapper and Chiralt 2018), glycerol (0.5% v/v) (Casariego et al. 2008; Lintang et al. 2021) and tween 80 (1.0%) (Sigma-Aldrich, Germany) were mixed in distilled water (2 L) and heated up to 90–95 °C. The higher concentrations of glycerol were suggested to decrease the wettability and adhesion coefficients of the edible coatings (Casariego et al. 2008). The solution was kept at that temperature for 30 min and mixed continuously. The prepared coating was cooled to room temperature and kept for another 2 h and applied to the fruits (Cano et al. 2015).

For the preparation of the EC+LEO, the same method for the edible coating preparation (described above) was used, but this time laurel essential oil (0.5%) dissolved in 70% ethyl alcohol (2:1 v/v) was also used together with corn starch and glycerol (Kahramanoğlu 2019). The dose of the laurel essential oil was selected based on previous studies with other essential oils, where doses of 0.5% was most effective and suggested to be more suitable for industrial applications (Kahramanoğlu et al. 2018; 2021).

Control, EC and EC+LEO treatments were all applied in the same way, by dipping the fruits in the prepared solutions and keeping them for 60 s. The fruits were then left to dry for 30 min, then their initial weight was measured and transferred to storage conditions (4.0 ± 1.0 °C temperature and 90–95% relative humidity). As mentioned above, three replications (total 18 fruits) from each treatment were taken out at 3-day intervals and following physical and chemical quality parameters were measured.

Data collection

At each measurement point, new weight of each fruit was measured, and the weight loss as percentage was determined by using the initial weights. Digital scales with an accuracy of ± 0.01 g were used to measure the fruit weights. Later, disease severity on fruits were reported according to the 0–5 scale of Romanazzi et al. (2013). According to this scale, 0 represents healthy fruits without mold; 1 is used for the fruits with 1–20% disease severity, 2 is used for 21–40% disease severity, 3 is used for 41–60% disease severity, 4 is used for 61–80% disease severity and 5 is used for 81–100% disease severity. Besides disease severity, the chemical spoilage of the fruits was also determined.

During storage, chemical reactions cause changes and spoilage in fruits as discoloration and unwanted off-flavor. This chemical spoilage was determined by following the 1–5 scale of Rux et al. (2017). In this scale, 5 refers to healthy fruits without chemical spoilage, 4: 1–25% spoilage, 3: 26–50% spoilage, 2: 51–75% spoilage and 1 indicates 76–100% spoilage. Next, the respiration rate of the fruits was measured by following the method described by Fonseca et al (2002).

A sealed container was used to measure the amount of carbon dioxide (CO_2) produced by the fruits and the results were used to calculate the CO_2 produced by 1 kg of fruit in 1 h and the results were expressed as mL CO_2 $kg^{-1}\cdot h^{-1}$. Fruit firmness ($kg\cdot cm^{-2}$) of each fruit was determined by a hand penetrometer (cylindrical probe: 2 mm diameter). Four different positions of each fruit (around the equator) were used to measure the flesh firmness. Soluble solids concentration of the fruits was determined as % brix by randomly selecting and measuring two fruits from each replication with a hand refractometer. The amount of ascorbic acid (AA: $mg\cdot 100\ g^{-1}$) of the fruits was determined by titrating the fruit juice with iodine solution (Skinner 1998), and the titratable acidity (TA) was determined by following the standard method of AOAC (1990) and expressed as $g\cdot 100\ g^{-1}$ citric acid.

Data Analysis

The raw data of the quality parameters were summarized with the help of Microsoft Excel, and the mean and standard deviations were calculated. Later, the raw data of each parameter for each measurement point was subjected to analysis of variance by SPSS 22.0, and, in case of a statistically significant difference between treatments, Tukey's HSD test at 5% significance level was used to quantify this difference.

RESULTS AND DISCUSSIONS

Chemical Composition of the Laurel Essential Oils

Seventeen different compounds were determined from the laurel essential oil (Table 1). These compounds can be categorized in three groups. The compounds from 1 to 9 in the table are monoterpene hydrocarbons, compounds from 10 to 16 are oxygenated monoterpenes and the final one is a phenylpropanoid. The three highest percentage compounds were recorded as eucalyptol (54.15%), α-terpinyl acetate (16.27%), and sabinene (6.08%). Eucalyptol is a colorless organic liquid compound, a cyclic ether, and a monoterpene. A-terpinyl acetate is a p-menthane monoterpenoid, and sabinene is a thujene that is a bicyclic monoterpene.

Table 1. Chemical compositions of the laurel essential oil isolated from the leaves of *L. nobilis*.

No	Compounds	RT	KI*	KI**	Concentration (%)
1	α-pinene	6.62	1034	1034	4.08
2	Camphene	7.66	1098	1099	0.12
3	β-pinene	8.48	1137	1136	1.76
4	Sabinene	8.77	1149	1149	6.08
5	α-Phellandrene	9.46	1180	1180	0.14
6	Limonene	10.08	1206	1206	1.12
7	β-Phellandrene	11.03	1241	1241	0.38
8	γ-Terpinene	11.18	1246	1246	0.76
9	p-cymene	12.72	1302	1302	1.76
10	Eucalyptol (1,8-Cineole)	12.12	1253	1281	54.15
11	Trans-sabinenehydrate	19.74	1459	1496	0.77
12	Linalool	20.72	1535	1535	1.61
13	Terpinen-4-ol	24.26	1645	1648	3.56
14	Bornylacetate	25.42	N/A	1706	0.56
15	α-Terpineol	26.73	1711	1729	4.00
16	α-Terpinyl acetate	27.58	1709	1743	16.27
17	Methyleugenol	38.01	2025	2024	2.22
	Total area				**99.34**

KI* = Kovats index literature; KI** = Kovats index determined.Source: Elaborated by the authors.

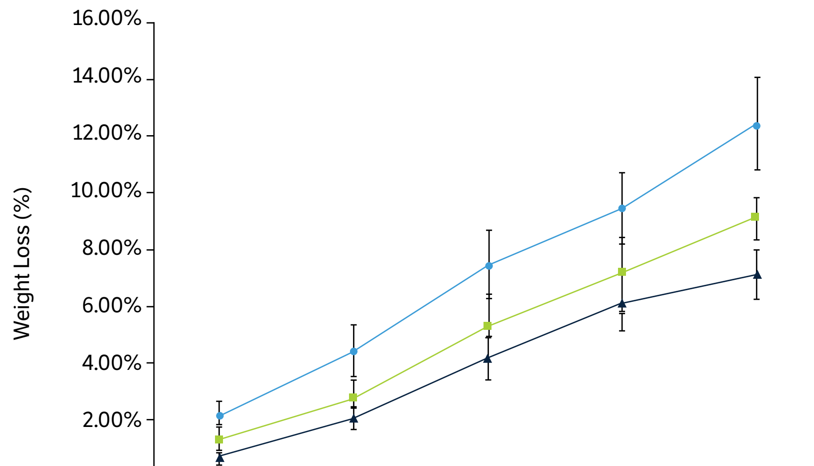
In a similar study, the eucalyptol percentage of leaf essential oils of *L. nobilis* grown in Colombia was noted to be around 22% (Quijano and Pino 2007). It is well known that the growing conditions significantly affect the phytochemical composition of plants (Okatan, 2020). On the other hand, Maciel et al. (2010) showed that there can be a significant variation among the eucalyptol compositions of the different varieties of a same species belonging to *Eucalyptus* spp. According to Caputo et al. (2017), in agreement with the current study, sabinene is also among the major compounds of the laurel essential oil.

In their study, Caputo et al. (2017) also reported that both the laurel essential oil and isolated eucalyptol have significant antimicrobial activity against several bacterial strains belonging to gram-negative and gram-positive bacteria. Eucalyptol is a major compound of the chemical composition of several herbs including basil, myrtle, sage, rosemary, thyme and etc. (Bahadırlı et al. 2020; Puvača et al. 2021). It is also reported to have a significant role in the antifungal and antioxidant activities of the oils (Mogoşanu et al. 2017). Besides the antifungal activity of eucalyptol, Lee et al. (2001) recommended that eucalyptol has fumigant activity against *Sitophilus oryzae* adults.

Effects on Quality Parameters

Weight loss

The weight loss of the strawberry fruits in each treatment showed a decreasing trend during storage (Fig. 1a). The weight loss of the control fruits was measured as 2.21% at the 3rd day of storage, which increased to 12.44% in 15 days of storage. At the same time, edible coating was found to provide favorable conditions for the reduction of weight loss. The fruits treated with edible coating was noted to have 9.06% weight loss in 15 days of storage. Enriching edible coating with laurel essential oil was found to increase the efficacy of the treatment. The fruits treated with edible coatings enriched with laurel essential oil had only 7.13% of weight loss in 15 days of storage. This is less than the weight loss of the control fruits measured at the 9th day of storage.



	Day 3	Day 6	Day 9	Day 12	Day 15
Control	2.21 % a	4.42 % a	7.47 % a	9.45 % a	12.44 % a
Edible Coating	1.30 % ab	2.75 % b	5.26 % b	7.10 % b	9.06 % b
EC + Laurel oil	0.79% b	2.08% c	4.19% c	6.11% c	7.13% c

Figure 1. Effects of edible coatings and edible coatings enriched with laurel essential oil on the weight loss of strawberry 'Camarosa' fruits during 15 days of storage.

Note. The marker points represent the mean of three replications with six fruits in each replication. The presence of the same letter or letters on the right side of the mean values on the same measurement day indicates that there is no significant difference between these values according to the Tukey's honestly significant difference test at 5% significance level. Source: Elaborated by the authors.

The main reasons of weight loss at fruits during storage are the movement of water from fruit to the atmosphere (Duan et al. 2011) and the loss of carbohydrate reserves by respiration (Kahramanoğlu 2017). The present results support the general knowledge that coatings reduce weight loss by providing barrier to moisture and oxygen. These findings were in conjunction with those suggested by Petriccione et al. (2015) for the strawberry cultivars 'Candonga', 'Jonica' and 'Sabrina'. In their research, the weight loss of chitosan (2%) coated fruits was recorded to vary from 6.97% to 8.98% at the end (9th day) of storage. Similarly, Ventura-Aguilar et al. (2018) reported that chitosan-based edible coatings provide favorable conditions for the storage of strawberries and reduce the weight loss of the fruits. Moreover, Khalifa et al. (2016) reported similar findings for chitosan-based edible coatings, where incorporation of edible coatings with lemongrass oil was found to provide higher performance in preventing weight loss. Strawberries stored with zein fiber was noted to show a significant reduction in weight loss, about 6% less than the control in 20 days of storage (Colussi et al. 2021). Additional to the benefits of laurel essential oil, glycerol, a hydrophilic polyol, promotes a better elasticity for the coating materials. This increases the hydrophobic character of the coating material and had a positive impact on the water permeation resistance of the edible coating (Pavinatto et al. 2020).

In a similar study, edible coatings developed from the combination of cassava starch and cinnamon or fennel essential oils were reported to have positive impacts on the storability of fresh-cut apples (Oriani et al. 2014). The researchers suggested that coatings increase water vapor resistance, decreased respiration rate and reduced the weight loss.

Incorporation of lemongrass essential oil into starch-based edible film was also suggested to reduce the weight loss of chili fruits and improve its storability. The lemongrass essential oil was noted to improve the mechanical properties of edible films and decreased tensile strength (Perdana et al. 2021). Lemongrass essential oils were also suggested to reduce the weight loss at papaya fruits when incorporated in starch-based edible coatings (Praseptiangga et al. 2017). Incorporation of essential oils such as oregano and black cumin, into starch-based edible films positively affects the mechanical properties (i.e., tensile strength) and water vapor barrier abilities of the materials, which helps to obtain less weight loss at the treated fruits (Šuput et al. 2016).

Respiration rate

The results recorded for the respiration rate (mL CO_2 kg^{-1}·h^{-1}) of strawberry fruits applied with different treatments and stored for 15 days are shown in Table 2. In all samples, the respiration rate of the fruits decreased during the first 3 days of storage, and then had an increasing trend. The samples stored without any treatment (control fruits) were all found to have higher respiration rate than the treated fruits. The lowest respiration rate was recorded for samples treated with edible coatings enriched with laurel essential oil. Those results are in agreement with the reports of Ventura-Aguilar et al. (2018), where coated fruits were recorded to have less respiration rate. This is in conjunction with the general knowledge too. Changing surrounding atmosphere of the fruits affect the respiration rate and reducing respiration rate would result with a reduction in the weight loss. In a similar study, Jalali et al. (2020) also noted that the respiration rate and CO_2 production increases during the storage and is very high at the end of the shelf life.

Table 2. Effects of edible coatings and edible coatings enriched with laurel essential oil on the quality parameters of strawberry 'Camarosa' fruits during 15 days of storage.

Treatments	Day 0	Day 3	Day 6	Day 9	Day 12	Day 15
	Respiration rate (mL CO_2·kg^{-1}·h^{-1})					
Control	9.4±0.3 a	2.2±0.4 a	12.3±0.1 a	17.2±0.9 a	21.9±0.5 a	25.3±3.6 a
Edible coating	9.4±0.3 a	2.0±0.2 b	8.2±0.1 b	11.7±0.6 b	15.7±0.7 b	23.7±0.9 a
EC + laurel EO	9.4±0.3 a	1.9±0.3 b	8.6±0.7 b	11.2±0.2 b	12.5±0.7 b	18.5±0.9 b
	Disease severity (0–5 scale)					
Control	0.0±0.0 a	0.0±0.0 a	0.0±0.0 a	0.4±0.5 a	1.8±0.6 a	3.2±0.7 a
Edible coating	0.0±0.0 a	0.0±0.0 a	0.0±0.0 a	0.1±0.3 b	1.1±0.5 b	1.8±0.7 b
EC + laurel EO	0.0±0.0 a	0.0±0.0 a	0.0±0.0 a	0.1±0.2 b	0.8±0.5 c	1.3±0.5 c
	Chemical spoilage (1–5 scale)					
Control	5.0±0.0 a	4.8±0.4 b	3.9±0.8 b	3.1±0.8 b	2.4±0.7 b	1.2±0.4 b
Edible coating	5.0±0.0 a	5.0±0.0 a	4.7±0.5 a	4.4±0.5 a	3.8±0.4 a	2.6±0.6 a
EC + laurel EO	5.0±0.0 a	5.0±0.0 a	4.9±0.2 a	4.7±0.5 a	4.2±0.6 a	3.3±0.5 a

continue...

Table 2. Continuation....

Treatments	Day 0	Day 3	Day 6	Day 9	Day 12	Day 15
	Fruit Firmness (kg·cm^{-2})					
Control	0.73±0.04 a	0.59±0.04 a	0.54±0.04 a	0.49±0.04 a	0.44±0.04 b	0.36±0.02 b
Edible coating	0.73±0.04 a	0.60±0.04 a	0.54±0.04 a	0.48±0.04 a	0.48±0.04 a	0.40±0.02 a
EC + laurel EO	0.73±0.04 a	0.61±0.04 a	0.55±0.04 a	0.50±0.04 a	0.50±0.04 a	0.42±0.02 a
	Ascorbic Acid (mg·100 g^{-1})					
Control	32.0±0.7 a	26.4±0.7 b	32.9±0.7 b	31.2±1.3 c	29.9±1.3 b	27.3±1.3 b
Edible coating	32.0±0.7 a	28.1±0.7 a	35.1±1.3 a	32.5±1.3 a	31.6±0.7 a	29.0±0.7 a
EC + laurel EO	32.0±0.7 a	27.7±0.7 ab	35.5±0.7 a	34.2±0.7 a	32.0±0.7 a	29.4±0.7 a
	Soluble Solids Concentration (%)					
Control	12.5±0.2 a	11.1±0.4 a	10.7±0.4 b	12.6±0.3 a	12.9±0.4 a	13.1±0.2 a
Edible coating	12.5±0.2 a	11.3±0.4 a	11.7±0.4 a	12.3±0.2 a	12.3±0.1 b	12.4±0.1 b
EC + laurel EO	12.5±0.2 a	11.3±0.4 a	11.2±0.5 a	12.3±0.4 a	12.4±0.3 b	12.4±0.3 b
	Titratable acidity (g·100 g^{-1} citric acid)					
Control	0.76±0.03 a	0.80±0.02 a	0.86±0.02 a	0.84±0.02 a	0.67±0.04 b	0.60±0.04 b
Edible coating	0.76±0.03 a	0.78±0.02 a	0.82±0.02 b	0.81±0.01 b	0.75±0.01 a	0.69±0.02 a
EC + laurel EO	0.76±0.03 a	0.79±0.02 a	0.82±0.02 b	0.81±0.02 b	0.72±0.01 ab	0.70±0.01 a

Note. Values are means ± standard deviations in the table and the same letter or letters near the values represent no significant difference among the treatments on the same measurement day according to the Tukey's HSD (honestly significant difference) test at 5% significance level. Source: Elaborated by the authors.

Disease severity

One of the most important findings of this research was the prevention of disease severity in fruits (Table 2). Accordingly, the disease severity started to be observed in the control fruits from the 6th day of storage and, at the end of the 15 days of storage period, the disease severity was determined as 3.22 according to the 0–5 scale. On the other hand, disease severity in samples treated with edible coatings and edible coatings enriched with laurel essential oil applications were determined as 1.83 and 1.33 at the end of the 15 days of storage period. Similar effects were previously noted for edible coating by several researchers (Khodaei et al. 2021; Pavinatto et al. 2020; Quintana et al. 2021; Ventura-Aguilar et al. 2018). In a similar study, Tajkarimi et al. (2010) reported that an edible coating supplemented with cinnamon oil increased the success in preventing disease severity. The success of edible coatings enriched with laurel essential oil in the present study can be attributed to the high contents of eucalyptol compound in the chemical structure of laurel essential oil. Quintana et al. (2021) reported that noncoated control strawberries had 31.7% decay in 10 days of storage, where the chitosan (enriched with rosemary or thyme oil) coated fruits had less than 10% decay. Similar success was also suggested by Martínez et al. (2018) for chitosan coatings enriched with *Thymus capitatus* essential oil.

Chemical spoilage

Chemical spoilage is a very important quality parameter, which significantly impact the consumer preferences. As for other quality parameters, chemical spoilage results of the present study have been found to support the positive results of both edible coating applications (Table 2). In line with these results, chemical spoilage was determined as 3.33 at the control fruits according to the 1–5 scale after 15 days of storage. At the same time, the chemical spoilage of the samples coated with edible coatings enriched with laurel essential oil was recorded to be only 1.22. This is also far below from the score (2.61) of samples treated with edible coatings. These results support other disease severity and weight loss results and are an important indicator of the success of the edible coating enriched with laurel essential oil.

Fruit firmness

Changes in the firmness of strawberry fruits during storage are given in Table 2. The firmness of strawberries 0.73 kg·cm^{-2} before storage. The firmness of control samples decreased to 0.36 kg·cm^{-2} in 15 days of storage. The highest fruit firmness was noted from the samples treated with edible coatings enriched with laurel essential oil as 0.42 kg·cm^{-2}. High respiration increases ripening and senescence, and causes an increase in the amount of water-soluble pectin in strawberry fruits. This may result with a change in molecular changes of polysaccharides in the cell wall, resulting in softening of strawberry fruits (Ventura-Aguilar et al. 2018). Prevention of this situation (by reducing the respiration rate) also helps to preserve the fruit firmness. In a similar study, Restrepo et al. (2010) reported that the fruit firmness of the samples treated with control was about three times less than the samples treated with *Aloe vera* gel and 0.1% carnauba wax coating. Decrease in fruit firmness may occur during postharvest storage, because of changes in the cell walls of strawberry fruits, which mainly involve a decrease in pectin levels (Yan et al. 2019).

Ascorbic acid

Ascorbic acid has an important role in fruits' defense mechanism against storage conditions and has a vital role in human nutrition. Similar to other quality parameters, both edible coating and edible coatings enriched with laurel essential oil practices contributed to the preservation of ascorbic acid content of fruits (Table 2). According to the results obtained, there was a decrease in the ascorbic acid content of the fruits in the first days of the storage, and an increase in ascorbic acid biosynthesis and consequently increase in the amount began to be observed in the following days. Similar observations by Atress et al. (2010) noted a decrease in the ascorbic acid content during storage. All these results revealed that edible coating applications have a positive effect on the amount of ascorbic acid, which has an important role in the fruit's antioxidant and defense mechanism, and this positive effect increased with the use of linseed oil.

Soluble solids concentration

The soluble solids concentration (SSC) was recorded as 12.53% at the beginning of storage. Results showed a decrease in the SSC in the first 6 days of storage and an increase thereafter. However, no significant difference was noted among the initial and final SSC contents of the fruits. These results support the findings of Bose et al. (2019), who reported a decrease in the SSC content of the fruits during 4–6 days of storage. The changes in the SSC content during the storage period was recorded to be similar with the change in ascorbic acid content (Table 2). This situation can be explained by the increase in solubility ratio due to the weight loss in fruits. In addition, the low loss and changes in fruits, especially at the coated samples, can be explained by the change in the air composition around the fruits and therefore the decrease in respiration rate. The reduction in respiration rate preserves the SSC content by reducing carbohydrate and sugar breakdown (Ventura-Aguilar et al. 2018).

Titratable acidity

Finally, it was observed that both treatments contributed to the slower changes in the titratable acidity (TA) content of fruits compared to the control (Table 2). According to the results obtained, the amount of acidity, which showed a slight increase in the first days of the preservation and decreased with the increase of spoilage in fruits, was less in samples coated with different treatments. Increase in respiration rate and fruit senescence are responsible for the reduction of different quality parameters, such as fruit weight, ascorbic acid, SSC and TA, which alter the characteristics of fruits (Liu et al. 2018). The changes in TA can also be explained by the use of organic acids after carbohydrates in fruit respiration (Nguyen et al. 2020). This explains the greater changes in the uncoated fruits and increase in the changes after a long period.

CONCLUSION

The current study suggests that the incorporation of laurel essential oil into the starch-based edible coating improve the efficacy of the coatings on the storability of strawberry fruits. According to the obtained results, the combination of edible coating with essential oil provided less weight loss during the 15 days of storage with only 7.13%. This high performance is strongly related with the reduced respiration rate of the coated fruits. The lowest disease severity score (1.3 ± 0.5) and lowest chemical spoilage (3.3 ± 0.5) were noted in the combined EC + laurel essential oil treatment. Accordingly, the average storage duration of strawberry 'Camarosa' fruits can be extended to 9 days with the application of edible coating, and up to 12 days with the edible coatings enriched with laurel essential oil. Confirmation of these results is highly necessary in other fruits. Then, new results would be beneficial for developing industrially applicable coating materials for fruit preservation.

AUTHORS' CONTRIBUTION

Conceptualization: Kahramanoğlu I., Bahadırlı N. P., Okatan V. and Wan C.; **Data Curation:** Kahramanoğlu I.; **Methodology:** Kahramanoğlu I., Bahadırlı N. P. and Okatan V.; **Investigation:** Kahramanoğlu I. and Bahadırlı N. P.; **Visualization:** Kahramanoğlu I. and Wan C.; **Writing – Original Draft:** Kahramanoğlu I., Bahadırlı N. P. and Okatan V.; **Writing – Review and Editing:** Kahramanoğlu I. and Wan C.; **Supervision:** Wan C.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ACKNOWLEDGMENTS

Not applicable.

REFERENCES

[AOAC] Association of Official Analytical Chemist. (1990). Official Methods of Analysis. Washington, DC: AOAC.

Atress, A. S. H., El-Mogy, M. M., Aboul-Anean, H. E. and Alsanius, B. W. (2010). Improving strawberry fruit storability by edible coating as a carrier of thymol or calcium chloride. Journal of Horticultural Science and Ornamental Plants, 2, 88-97.

Bahadırlı, N. P., Kahramanoğlu, İ. and Wan, C. (2020). Exposure to volatile essential oils of myrtle (*Myrtus communis* L.) leaves for improving the postharvest storability of fresh loquat fruits. Journal of Food Quality, 2020, 8857669. https://doi.org/10.1155/2020/8857669

Bose, S. K., Howlader, P., Jia, X., Wang, W. and Yin, H. (2019). Alginate oligosaccharide postharvest treatment preserve fruit quality and increase storage life via Abscisic acid signaling in strawberry. Food Chemistry, 283, 665-674. https://doi.org/10.1016/j.foodchem.2019.01.060

Caleb, O. J., Wegner, G., Rolleczek, C., Herppich, W. B., Geyer, M. and Mahajan, P. V., (2016). Hot water dipping: Impact on postharvest quality, individual sugars, and bioactive compounds during storage of 'Sonata' strawberry. Scientia Horticulturae, 210, 150-157. https://doi.org/10.1016/j.scienta.2016.07.021

Cano, A., Fortunati, E., Cháfer, M., Kenny, J. M., Chiralt, A. and González-Martínez, C. (2015). Properties and ageing behaviour of pea starch films as affected by blend with poly(vinyl alcohol). Food Hydrocolloids, 48, 84-93. https://doi.org/10.1016/j.foodhyd.2015.01.008

Caputo, L., Nazzaro, F., Souza, L. F., Aliberti, L., De Martino, L., Fratianni, F. and De Feo, V. (2017). *Laurus nobilis*: Composition of essential oil and its biological activities. Molecules, 22, 930. https://doi.org/10.3390/molecules22060930

Casariego, A., Souza, B. W. S., Vicente, A. A., Teixeira, J. A., Cruz, L. and Díaz, R. (2008). Chitosan coating surface properties as affected by plasticizer, surfactant and polymer concentrations in relation to the surface properties of tomato and carrot. Food Hydrocolloids, 22, 1452-1459. https://doi.org/10.1016/j.foodhyd.2007.09.010

Chen, J., Shen, Y., Chen, C. and Wan, C. (2019). Inhibition of key citrus postharvest fungal strains by plant extracts in vitro and in vivo: A review. Plants, 8, 26. https://doi.org/10.3390/plants8020026

Colussi, R., Silva, W. M. F., Biduski, B., El Halal, S. L. M., Zavareze, E. R. and Dias, A. R. G. (2021). Postharvest quality and antioxidant activity extension of strawberry fruit using allyl isothiocyanate encapsulated by electrospun zein ultrafine fibers. LWT, 143, 111087. https://doi.org/10.1016/j.lwt.2021.111087

Cordenunsi, B. R., Genovese, M. I. and Nascimento, J. R. O., Hassimotto, N. M. A., Santos, R. J. and Lajolo, F. M. (2005). Effects of temperature on the chemical composition and antioxidant activity of three strawberry cultivars. Food Chemistry, 91, 113-121. https://doi.org/10.1016/j.foodchem.2004.05.054

De Corato, U., Maccioni, O., Trupo, M. and Di Sanzo, G. (2010). Use of essential oil of *Laurus nobilis* obtained by means of a supercritical carbon dioxide technique against post harvest spoilage fungi. Crop Protection, 29, 142-147. https://doi.org/10.1016/j.cropro.2009.10.012

Duan, J., Wu, R., Strik, B. C. and Zhao, Y. (2011). Effects of edible coatings on the quality of fresh blueberries (Duke and Elliott) under commercial storage conditions. Postharvest Biology and Technology, 59, 71-79. https://doi.org/10.1016/j.postharvbio.2010.08.006

Ferreira, A. R., Alves, V. D. and Coelhoso, I. M. (2016). Polysaccharide-based membranes in food packaging applications. Membranes, 6, 22. https://doi.org/10.3390/membranes6020022

Fonseca, S. C., Oliveira, F. A. and Brecht, J. K. (2002). Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: A review. Journal of Food Engineering, 52, 99-119. https://doi.org/10.1016/S0260-8774(01)00106-6

Hashemi, M., Dastjerdi, A. M., Mirdehghan, S. H., Shakerardekani, A., and Golding, J. B. (2021). Incorporation of *Zataria multiflora* Boiss essential oil into gum Arabic edible coating to maintain the quality properties of fresh in-hull pistachio (*Pistacia vera* L.). Food Packaging and Shelf life, 30, 100724. https://doi.org/10.1016/j.fpsl.2021.100724

Jalali, A., Linke, M., Geyer, M. and Mahajan, P. V. (2020). Shelf life prediction model for strawberry based on respiration and transpiration processes. Food Packaging and Shelf Life, 25, 100525. https://doi.org/10.1016/j.fpsl.2020.100525

Kader, A. A. (1991). Quality and its maintenance in relation to the postharvest physiology of strawberry. In A. Dale and J. J. Luby (Eds.), The strawberry into the 21st century (p. 145-152). Portland: Timber Press.

Kahramanoğlu, İ. (2017). Introductory chapter: Postharvest physiology and technology of horticultural crops. In Postharvest Handling (p.1-5). London: IntechOpen. https://doi.org/10.5772/intechopen.69466

Kahramanoğlu, İ. (2019). Effects of lemongrass oil application and modified atmosphere packaging on the postharvest life and quality of strawberry fruits. Scientia Horticulturae, 256, 108527. https://doi.org/10.1016/j.scienta.2019.05.054

Kahramanoğlu, İ. (2020). Preserving postharvest storage quality of fresh loquat fruits by using different bio-materials. Journal of Food Science and Technology, 57(8), 3004-3012. https://doi.org/10.1007/s13197-020-04333-5

Kahramanoğlu, I. (2021). Use of black cumin oil and liquorice syrup to maintain the postharvest quality of fully ripe apricot fruits var. 'Thyrinte'. European Journal of Horticultural Science, 86(3), 260-269. https://doi.org/10.17660/eJHS.2021/86.3.5

Kahramanoğlu, İ., Aktaş, M. and Gündüz, Ş. (2018). Effects of fludioxonil, propolis and black seed oil application on the postharvest quality of "Wonderful" pomegranate. PLoS ONE, 13, e0198411. https://doi.org/10.1371/journal.pone.0198411

Khalifa, I., Barakat, H., El-Mansy, H. A. and Soliman, S. A. (2016). Enhancing the keeping quality of fresh strawberry using chitosan-incorporated olive processing wastes. Food Bioscience, 13, 69-75. https://doi.org/10.1016/j.fbio.2015.12.008

Khodaei, D., Hamidi-Esfahani, Z. and Rahmati, E. (2021). Effect of edible coatings on the shelf-life of fresh strawberries: A comparative study using TOPSIS-Shannon entropy method. NFS Journal, 23, 17-23. https://doi.org/10.1016/j.nfs.2021.02.003

Koch, S., Epp, A., Lohmann, M. and Böl, G. F. (2017). Pesticide residues in food: attitudes, beliefs, and misconceptions among conventional and organic consumers. Journal of Food Protection, 80, 2083-2089. https://doi.org/10.4315/0362-028X.JFP-17-104

Lee, B. H., Choi, W. S., Lee, S. E. and Park, B. S. (2001). Fumigant toxicity of essential oils and their constituent compounds towards the rice weevil, *Sitophilus oryzae* (L.). Crop Protection, 20, 317-320. https://doi.org/10.1016/S0261-2194(00)00158-7

Lintang, M., Tandi, O., Layuk, P., Karouw, S. and Dirpan, A. (2021). Characterization edible films of sago with glycerol as a plasticizer. IOP Conference Series: Earth and Environmental Science, 807, 022070. https://doi.org/10.1088/1755-1315/807/2/022070

Liu, C., Zheng, H., Sheng, K., Liu, W. and Zheng, L. (2018). Effects of melatonin treatment on the postharvest quality of strawberry fruit. Postharvest Biology and Technology, 139, 47-55. https://doi.org/10.1016/j.postharvbio.2018.01.016

Maciel, M. V., Morais, S. M., Bevilaqua, C. M. L., Silva, R. A., Barros, R. S., Sousa, R. N. and Souza-Neto, M. A. (2010). Chemical composition of Eucalyptus spp. essential oils and their insecticidal effects on *Lutzomyia longipalpis*. Veterinary parasitology, 167, 1-7. https://doi.org/10.1016/j.vetpar.2009.09.053

Martínez, K., Ortiz, M., Albis, A., Gutiérrez Castañeda, C. G., Valencia, M. E. and Grande Tovar, C. D. (2018). The effect of edible chitosan coatings incorporated with *Thymus capitatus* essential oil on the shelf-life of strawberry (*Fragaria x ananassa*) during cold storage. Biomolecules, 8, 155. https://doi.org/10.3390/biom8040155

Mogoşanu, G. D., Grumezescu, A. M., Bejenaru, C. and Bejenaru, L. E. (2017). Natural products used for food preservation. In A. M. Grumezescu (Ed.), Food Preservation (p. 365-411). London: Academic Press. https://doi.org/10.1016/B978-0-12-804303-5.00011-0

Müller, C. M., Yamashita, F. and Laurindo, J. B. (2008). Evaluation of the effects of glycerol and sorbitol concentration and water activity on the water barrier properties of cassava starch films through a solubility approach. Carbohydrate Polymers, 72, 82-87. https://doi.org/10.1016/j.carbpol.2007.07.026

Nguyen, V. T. B., Nguyen, D. H. H. and Nguyen, H. V. H. (2020). Combination effects of calcium chloride and nano-chitosan on the postharvest quality of strawberry (Fragaria x ananassa Duch.). Postharvest Biology and Technology, 162, 1-8. https://doi.org/10.1016/j.postharvbio.2019.111103

Nor, S. M. and Ding, P. (2020). Trends and Advances in Edible Biopolymer Coating for Tropical Fruit: A Review. Food Research International, 109208. https://doi.org/10.1016/j.foodres.2020.109208

Okatan, V. (2020). Antioxidant properties and phenolic profile of the most widely appreciated cultivated berry species: A comparative study. Folia Horticulturae, 32, 79-85. https://doi.org/10.2478/fhort-2020-0008

Oriani, V. B., Molina, G., Chiumarelli, M., Pastore, G. M. and Hubinger, M. D. (2014). Properties of cassava starch-based edible coating containing essential oils. Journal of food science, 79, E189-E194. https://doi.org/10.1111/1750-3841.12332

Ortega-Toro, R., Morey, I., Talens, P. and Chiralt, A. (2015). Active bilayer films of thermoplastic starch and polycaprolactone obtained by compression molding. Carbohydrate polymers, 127, 282-290. https://doi.org/10.1016/j.carbpol.2015.03.080

Oszmiański, J. and Wojdyło, A. (2009). Comparative study of phenolic content and antioxidant activity of strawberry puree, clear, and cloudy juices. European Food Research and Technology, 228, 623-631. https://doi.org/10.1007/s00217-008-0971-2

Pavinatto, A., Mattos, A. V. A., Malpass, A. C. G., Okura, M. H., Balogh, D. T. Sanfelice, R. C. (2020). Coating with chitosan-based edible films for mechanical/biological protection of strawberries. International Journal of Biological Macromolecules, 151, 1004-1011. https://doi.org/10.1016/j.ijbiomac.2019.11.076

Perdana, M. I., Ruamcharoen, J., Panphon, S. and Leelakriangsak, M. (2021). Antimicrobial activity and physical properties of starch/chitosan film incorporated with lemongrass essential oil and its application. LWT, 141, 110934. https://doi.org/10.1016/j.lwt.2021.110934

Petriccione, M., Mastrobuoni, F., Pasquariello, M. S., Zampella, L., Nobis, E., Capriolo, G. and Scortichini, M. (2015). Effect of chitosan coating on the postharvest quality and antioxidant enzyme system response of strawberry fruit during cold storage. Foods, 4, 501-523. https://doi.org/10.3390/foods4040501

Praseptiangga, D., Utami, R., Khasanah, L. U., Evirananda, I. P. and Kawiji (2017). Effect of cassava starch-based edible coating incorporated with lemongrass essential oil on the quality of papaya MJ9. In IOP Conference Series: Materials Science and Engineering 176, 012054. https://doi.org/10.1088/1757-899X/176/1/012054

Puvača, N., Milenković, J., Galonja Coghill, T., Bursić, V., Petrović, A., Tanasković, S., Pelić, M., Pelić, D. L. and Miljković, T. (2021). Antimicrobial activity of selected essential oils against selected pathogenic bacteria: *In vitro* study. Antibiotics, 10, 546. https://doi.org/10.3390/antibiotics10050546

Quijano, C. E. and Pino, J. A. (2007). Characterization of the leaf essential oil from laurel (*Laurus nobilis* L.) grown in Colombia. Revista CENIC Ciências Químicas, 38, 371-374.

Quintana, S. E., Llalla, O., García-Risco, M. R. and Fornari, T. (2021). Comparison between essential oils and supercritical extracts into chitosan-based edible coatings on strawberry quality during cold storage. The Journal of Supercritical Fluids, 171, 105198. https://doi.org/10.1016/j.supflu.2021.105198

Restrepo, F., Jorge, I. and Aristizábal, T. (2010). Conservación de fresa (*Fragaria* × *ananassa* Duch cv. *Camarosa*) mediante la aplicación de recubrimientos comestibles de gel mucilaginoso de penca sábila (*Aloe barbadensis* Miller) y cera de carnaúba. Vitae, 17, 252-263.

Rhim, J.-W., Park, H.-M. and Ha, C.-S. (2013). Bio-nanocomposites for food packaging applications. Progress in Polymer Science, 38, 1629-1652. https://doi.org/10.1016/j.progpolymsci.2013.05.008

Ribeiro, C., Vicente, A. A., Teixeira, J. A. Miranda, C. (2007). Optimization of edible coating composition to retard strawberry fruit senescence. Postharvest Biology and Technology, 44, 63-70. https://doi.org/10.1016/j.postharvbio.2006.11.015

Riva, S. C., Opara, U. O. and Fawole, O. A. (2020). Recent developments on postharvest application of edible coatings on stone fruit: A review. Scientia Horticulturae, 262, 109074. https://doi.org/10.1016/j.scienta.2019.109074

Romanazzi, G., Feliziani, E., Santini, M. and Landi, L. (2013). Effectiveness of postharvest treatment with chitosan and other resistance inducers in the control of storage decay of strawberry. Postharvest Biology and Technology, 75, 24-27. https://doi.org/10.1016/j.postharvbio.2012.07.007

Rux, G., Caleb, O. J., Geyer, M. and Mahajan, P. V. (2017). Impact of water rinsing and perforation-mediated MAP on the quality and off-odour development for Rucola. Food Packaging and Shelf Life, 11, 21-30. https://doi.org/10.1016/j.fpsl.2016.11.003

Sapper, M. and Chiralt, A. (2018). Starch-based coatings for preservation of fruits and vegetables. Coatings, 8, 152. https://doi.org/10.3390/coatings8050152

Skinner, J. (1998). Experiments in Chemistry, Measuring the amount of vitamin C in fruit drinks. In Microscale chemistry. Londres: Royal Society of Chemistry.

Šuput, D., Lazić, V., Pezo, L., Markov, S., Vaštag, Z., Popović, L., Radulović, A., Ostojić, S., Zlatanović, S. and Popović, S. (2016). Characterization of starch edible films with different essential oils addition. Polish Journal of Food and Nutrition Sciences, 66, 277-285. https://doi.org/10.1515/pjfns-2016-0008

Tajkarimi, M. M., Ibrahim, S. A. and Cliver, D. O. (2010). Antimicrobial herb and spice compounds in food. Food Control, 21, 1199-1218. https://doi.org/10.1016/j.foodcont.2010.02.003

Thakur, V. K. and Thakur, M. K. (2015). Handbook of sustainable polymers: Processing and applications. New York: Jenny Stanford Publishing. https://doi.org/10.1201/b19600

Ventura-Aguilar, R. I., Bautista-Baños, S., Flores-García, G. and Zavaleta-Avejar, L. (2018). Impact of chitosan based edible coatings functionalized with natural compounds on *Colletotrichum fragariae* development and the quality of strawberries. Food chemistry, 262, 142-149. https://doi.org/10.1016/j.foodchem.2018.04.063

Wan, C., Kahramanoğlu, İ., & Okatan, V. (2021). Application of plant natural products for the management of postharvest diseases in fruits. Folia Horticulturae, 33(1), 203-215.

Watkins, C. B. and Nock, J. F. (2012). Production guide for storage of organic fruits and vegetables No. 10. New York: Cornell University.

Yan, J., Luo, Z., Ban, Z., Lu, H., Li, D., Yang, D., Aghdam, M. S. and Li, L. (2019). The effect of the layer-by-layer (LBL) edible coating on strawberry quality and metabolites during storage. Postharvest Biology and Technology, 147, 29-38. https://doi.org/10.1016/j.postharvbio.2018.09.002