Çukurova Tarım Gıda Bil. Der. Çukurova J. Agric. Food Sci.
39(1):192-207
doi: 10.36846/CJAFS.2024.143

Research Article

Potential Application of Chitosan Based Edible Coating Combined with Pomegranate and Lemon Peel Phenolic Extract on Apple and Kiwifruit Slices: Physical, Chemical and Sensory Characteristics

İrem Burun[1], Gozde Kutlu[2*], Fatih Tornuk[1,3]

ABSTRACT

The aim of this study was to assess the impact of different coatings, namely neat chitosan and chitosan combined with pomegranate and lemon extract, on the quality of apple and kiwifruit slices during 21 days of storage at 8°C, and the results were compared to the control samples (uncoated). Results showed that dry matter content of control samples was initially lower than that of the coated ones, while it increased during the storage. Phenolic added chitosan coatings consistently resulted in higher dry matter levels than neat chitosan. During storage, pH values ranged from 4.40 to 4.74 for apple slices and from 3.68 to 4.05 for kiwifruit slices, respectively. The pH value of the control samples was higher on the 7th day compared to the initial measurement, and then gradually decreased for both apple and kiwifruit slices. Chitosan alone slightly increased apple slices' pH, while the combination of chitosan+phenolic extracts decreased it. Uncoated apple slices experienced ongoing weight loss of up to 6.64%, compared to 2.93% for kiwifruit slices during storage, indicating a higher rate of weight loss in apples than in kiwifruits. Furthermore, negative weight loss was observed in the coated fruits. Coating aplications caused significant changes in *L**, *a** and *b** values, with kiwifruit slices consistently exhibiting lower color values compared to apples. No visual fungal decay was observed in any sample during the storage. Uncoated samples had higher sensory scores at the beginning of the storage while coating application provided better scores as the storage progresses, showing the preservative effect of the chitosan-based coating on the fruit slices. Overall, this study confirmed that coating of kiwifruit and apple slices with chitosan or chitosan + lemon/pomegranate phenolics could provide better quality and longer shelf life.

Keywords: Postharvest, fruit preservation, chitosan, coating.

Elma ve Kivi Dilimlerinde Nar ve Limon Kabuğu Fenolik Ekstraktı ile Birleştirilmiş Kitosan Bazlı Yenilebilir Kaplamanın Potansiyel Uygulaması: Fiziksel, Kimyasal ve Duyusal Özellikler

ÖZ

Bu çalışmanın amacı, kitosan ve kitosan + nar ve limon ekstraktı kullanımının, elma ve kivi dilimlerinin kalitesi üzerine etkisini, kaplanmamış örneklerle karşılaştırarak 21 gün boyunca 8°C'de değerlendirmektir. Elde edilen bulgular, depolama süresince kitosan kaplaması ve kitosan+fenolik ekstrakt kombinasyonunun kontrol örnekleri ile karşılaştırıldığında elma ve kivi dilimlerinin kuru madde içeriğinin arttırdığını göstermiştir. Fenolik eklenmiş kitosan kaplamalar, saf kitosan kaplamaya göre daha yüksek kuru madde içeriğine sahiptir. Depolama süresince, pH değerleri elma dilimleri için 4,40 ile 4,74 arasında iken kivi dilimleri için 3,68 ile 4,05 arasında değişmiştir. Kontrol örneklerinin pH değeri, elma ve kivi dilimleri için başlangıçtaki ölçüm sonuçlarına göre 7. günde daha yüksek seviyededir ve daha sonra her iki dilim için de bu değerler kademeli olarak azalmıştır. Yalnızca kitosan kullanımı, elma dilimlerinin pH değerini hafifçe arttırmış, fenolik ekstraktların kitosan ile birlikte kullanımı ise pH değerini azaltmıştır. Kaplanmamış elma dilimlerinde depolama süresince %6,64'e kadar olan bir ağırlık kaybı yaşanırken bu oran kivi dilimlerinde %2,93'tür. Bu da elmaların kivilerden daha yüksek bir ağırlık kaybı oranına sahip olduğunu göstermektedir. Ayrıca, kaplanmış meyvelerde negatif ağırlık kaybı gözlemlenmiştir. Kaplama uygulamaları *L*, a** ve *b** değerlerinde

Yayın Kuruluna Geliş Tarihi: 17.05.2024
Kabul Tarihi: 25.06.2024

[1] Yildiz Technical University, Faculty of Chemical and Metallurgical Engineering, Department of Food Engineering, Davutpasa Campus, Istanbul, Türkiye.
[2] Ankara Medipol University, Faculty of Fine Arts, Design and Architecture, Department of Gastronomy and Culinary Arts, Ankara, Türkiye.
[3] Sivas Cumhuriyet University, Faculty of Health Sciences, Department of Nutrition and Dietetics, 58140 Sivas, Türkiye.
*E-posta: *gozcelk@gmail.com*

önemli değişikliklere neden olmuş, kivi dilimleri sürekli olarak elmalara göre daha düşük renk değerleri sergilemiştir. Herhangi bir örnekte gözle görülür bir küf oluşumu gözlemlenmemiştir. Kaplanmamış örnekler depolamanın başlangıcında daha yüksek duyusal puanlar alırken kaplama uygulanan örnekler depolama ilerledikçe daha iyi puanlar almıştır. Bu da kitosan tabanlı kaplamanın meyve dilimleri üzerindeki koruyucu etkisini göstermektedir. Genel olarak, bu çalışma, elma ve kivi dilimlerinin kitosan, kitosan+limon/nar fenolik ekstraktları ile kaplanmasının daha iyi kalite ve daha uzun raf ömrü sağlayabileceğini doğrulamıştır.
Anahtar kelimeler: Hasat sonrası, meyve koruma, kitosan, kaplama.

ORCID ID (Yazar sırasına göre)
0009-0008-0043-3670, 0000-0001-7111-1726, 0000-0002-7313-0207

Introduction

The susceptibility of fruits to decay, their sensitivity to low temperatures, and their overall perishability, caused by rapid ripening and softening, pose limitations on their storage, handling, and transportation capabilities (Abbasi et al., 2009). The application of edible coatings on the surface of fruits, combined with cold storage, is a promising method for extending their shelf life, maintaining quality, protecting against postharvest diseases, and minimizing losses of these highly perishable fruits (Badawy et al., 2017). The Food and Drug Administration (FDA) and the United States Department of Agriculture (USDA) define "fresh" and "minimally processed" products as fruits and vegetables that are freshly cut, washed, packaged, and maintained at refrigerator temperature (De Corato, 2019). Minimally processed fruits and vegetables are also described as "maintained products" because they naturally offer a high standard of quality, characterized by genuine freshness and a rich content of essential nutrients such as minerals, fiber, vitamins, and antioxidants (De Corato, 2019).

Chitosan (CS, 2-amino-2-deoxy-D-glycopyranose), derived from chitin (2-acetamide-2-deoxy-D-glycopyranose) through a process called deacetylation, is a natural polysaccharide (Gomes et al., 2020). CS, an USFDA (the United States Food and Drug Administration)-approved "Generally Recognized as Safe" (GRAS) food additive, is widely used in the food industry. Its application is attributed to its mucoadhesiveness, biocompatibility, biodegradability, non-toxicity, non-immunogenicity, and its proven ability to inhibit various fungal pathogens affecting plants (Atlar et al., 2024; Badawy et al., 2017; Feyzioglu & Tornuk, 2016; Gomes et al., 2020; Kutlu, 2021). When applied as a coating on fruits and vegetables, CS creates a semi-permeable barrier that slows down respiration and ripening of freshly cut fruit. Consequently, these coatings help minimize moisture loss, weight loss, and contribute to maintaining the overall quality (Badawy et al., 2017). Films and edible coatings are described as thin layers of material that create a protective barrier around edible items, allowing them to be ingested with the coated product (Abbasi et al., 2009).

The peels of vegetables and fruits, often discarded as waste, have the potential to serve as valuable additives due to their antifungal and antimicrobial properties, making them suitable for inclusion in coating formulations (Nair et al., 2018). Lemons are rich in essential natural nutrients, including phenolic compounds (*e.g.* eriocitrin, coumarins, limonoid glycosides) dietary fiber, essential oils, and carotenoids. Recent evidence suggests that lemons possess antibacterial, antioxidant, and anti-inflammatory features, contributing to their beneficial impacts on overall health (Xi et al., 2017). The pomegranate peel is widely recognized as a rich source of phenolic acids, flavonoids, and tannins (including ellagitannins like punicalagin and punicalin). These compounds have attracted significant interest and favour for the development of novel antimicrobials due to their potential health benefits and wide range of biological functions (Singh et al., 2019). The simultaneous use of CS and extracts from fruit processing by-products holds the potential not only to enhance the value of these materials but also to advance the development of innovative and eco-friendly fruit protective technologies (Gomes et al., 2020). There have been numerous studies in the literature concerning the coating of apples (Qi et al., 2011; Liu et al., 2016; Garrido Assis et al., 2011) and kiwifruit slices (Kaya et al., 2016; Guroo et al., 2021) with CS. Nevertheless, upon reviewing previous studies in the literature, it was found that there were no available scientific studies on the physical, chemical, and sensory attributes of apple and kiwifruit slices coated with pomegranate (PPE) and lemon peel phenolic extract (LPE) combined with CS as an edible coating. In this context, the present study was undertaken (i) to prepare edible coatings formulated with CS and phenolic rich extracts from pomegranate and lemon peel, and (ii) to determine the effects of these coatings, including only CS and CS-phenolic extracts, compared to uncoated apple and kiwi fruits, on some physical, chemical and sensory properties.

Material and method

Materials

High molecular weight chitosan was obtained from Sigma-Aldrich (Germany). Fresh pomegranate (*Punica granatum* L.) peels were obtained from local pomegranate juice sellers, while lemon (*Citrus limon* Burm.) peels were collected as household waste. The peels were rapidly transferred to the laboratory and dried in a fan-assisted oven (Memmert UF-110, Germany) at 40°C for 18 h. The peels were then ground using a coffee grounder to provide powders and stored at +4°C in polyethylene plastic bags until extraction.

Fresh apple (*Pyrus malus* L.) and kiwifruits (*Actinidia deliciosa* cv. 'Hayward') were obtained from a local supermarket in Istanbul (Türkiye) and immediately transported to the laboratory. After peeling, the fruits are sliced at room temperature with a sharp stainless-steel knife with a thickness of 1 cm and an average weight of 1 g.

Extraction of phenolic compounds from lemon and pomegranate peels

A mixture containing 25% lemon peel and 75% pomegranate peel, totaling 900 g of ground peels, was mixed with distilled water at a ratio of 1/9 (w:v). The mixture was stirred at 200 rpm using a magnetic stirrer (IKA C-MAG HS 7, Germany) at room temperature for 24 h. Subsequently, centrifugation (Thermo Scientific, Centrifuge Multifuge X3 FR) was performed. The resulting supernatant was obtained and freeze-dried in a lyophilizer (Christ β 1,8-LSC plus, Martin Christ GmbH, Osterode am Harz, Germany) to obtain the dried extracts.

Preparation of coating solution

The CS-based coating solution was prepared by dissolving CS at a concentration of 2% (w:v, decided by preliminary experiments) in diluted acetic acid (1%, v:v) containing 0.05 g/100 ml of Tween 80, with pH values adjusted to 5.6 using 1 mol/L NaOH. After complete dissolution, the phenolic extract consisting of LPE and PPE was added to the CS solution at a 1% ratio and mixed using a magnetic stirrer for 6 h at room temperature and coating solutions were obtained. A neat chitosan coating solution without the extract was also prepared.

Coating of kiwi and apple slices

The fruit slices were directly immersed in the prepared coating solution at room temperature for 2-3 min, and then applied coating was left wet for a few min after draining the slices. Subsequently, the fruit slices were dried in an oven at 35°C for 18 h. The coated fruits were stored at 8°C for 21 days in plastic storage containers 85–90% relative humidity for the further analyses. Fruit samples were coded as follows: CA, uncoated apple slices; CCA, apple slices coated with neat chitosan; PCCA, apple slices coated with chitosan+phenolic extract; CK: uncoated kiwifruit slices; CCK, kiwifruit slices coated with neat chitosan; and PCCK, kiwifruit slices coated with chitosan+phenolic extract. On the 0^{th}, 7^{th}, 14^{th}, and 21^{st} days of storage, the fruit samples were analyzed.

Characterization of coated fruit slices

Determination of dry matter content

The gravimetric method was used to determine the dry matter content of the samples (3 g). The difference of weights of fruit samples before and after drying at 105°C for 18 h was calculated and given as percentage (AOAC International, 2002).

pH determination

For determination of pH values of the fruit slices, 10 g of the sample was weighed, and combined with 90 g of distilled water. The mixture was homogenized using a high-shear homogenizer (Ultra Turrax, Daihan, HG-15D), and the pH values of the fruit samples were measured directly by immersing the pH-meter probe in the mixture at ambient temperature (Mannozzi et al., 2017).

Weight loss
The fruit samples were weighed on the 0^{th}, 7^{th}, 14^{th}, and 21^{st} days, and the weight loss was given as percent (AOAC, 1994).

Color measurement
A Hunter Lab Colorflex (CFLX 45–2 Model Colorimeter, Hunter Lab, Reston, VA) was used to measure the $L*$ (lightness), $a*$ (redness/greenness), and $b*$ (yellowness/blueness) values of the samples (Mannozzi et al., 2017).

Visual observation of fungal decay
The fruit samples were visually inspected on the 0^{th}, 7^{th}, 14^{th}, and 21^{st} days of storage to identify any signs of fugal decay. They were considered infected if a visible lesion was observed (Benhabiles et al., 2013).

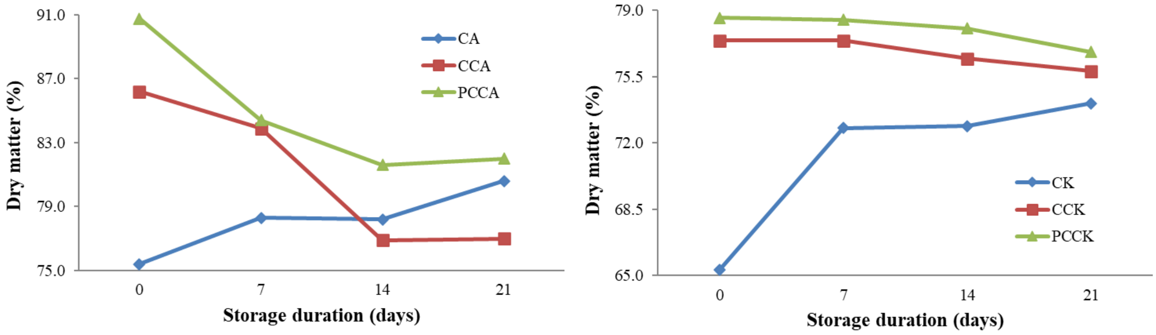
Sensory analysis
The sensory properties of the fruit samples were examined on days 0, 7, 14, and 21. A hedonic scale ranging from 1 to 5 was used to evaluate the texture, taste, and odor of the samples by the panelists (n=8) (Han et al., 2006).

Statistical evaluation
The findings, derived from a minimum of three parallel analyses, were presented as mean ± standard deviation. One-way analysis of variance (ANOVA) (Student's *t* test; $p < 0.05$) was performed using JMP Statistical Software version 6 (SAS Institute, Cary, NC) to determine the significant differences between the data (Kutlu et al., 2024).

Results and Discussion

Dry matter contents
During the 21 days of storage, the dry matter contents of CA, CCA, and PCCA samples ranged from 75.4% to 86.2% (Figure 1a). The dry matter contents of the CA samples increased until the 7^{th} day, remained nearly constant on the 7^{th} and 14^{th} days, and showed a significant increase on the 21^{st} storage day compared to other tested storage days. On the other hand, CCA and PCCA exhibited similar trends in dry matter changes during storage. According to this trend, the dry matter decreased until the 14^{th} day and remained almost constant between the 14^{th} and 21^{st} days. In a related study, Mannozzi et al. (2021) evaluated the effects of different coating methods (dipping and spraying) and coating solutions (alginate, 5% and 10%) on the fresh-cut mellons. They found a significant decrease in the moisture content of coated fresh-cut melons over 11 days. Moreover, Mannozzi et al. (2017) studied the effects of various coatings (pectin and/or sodium alginate) on blueberries and found that the dry matter content tended to rise over 14 storage days in both untreated and coated samples. However, in the study by Mannozzi et al. (2018), blueberry fruits coated with chitosan + proanthocyanidins showed no statistically significant changes in dry matter content over 14 days, whereas in chitosan-coated samples, there was a slight increase until the 10^{th} day and a decrease on the 14^{th} day.

During the storage duration, the dry matter contents for CK, CCK, and PCCK samples were as follows: CK ranged from 65.3% (0^{th} day) to 74.1% (21^{st} day), CCK ranged from 75.8% (21^{st} day) to 77.4% (0^{th} and 7^{th} day), and PCCK ranged from 76.8% (21^{st} day) to 78.6% (0^{th} day) (Figure 1b). The dry matter contents of CK samples increased until the 7^{th} day, remained nearly stable on the 7^{th} and 14^{th} days, and increased again on the 21^{st} day. The dry matter contents of CCK and PCCK samples decreased until the 14^{th} day, and although there was a slight increase between the 14^{th} and 21^{st} days, this increase was found to be statistically insignificant ($p>0.05$). Accordingly, the coated kiwifruit slices showed greater stability in terms of changes in dry matter content during storage compared to the control samples. These results showed that the dry matter content of both apple and kiwifruit slices increased when they were only subjected to CS coating or when they were coated with a combination of phenolic extracts and CS, compared to the control samples. This rise can be due to the the presence of coating materials (CS/ CS+phenolic extracts) in coated fruits (Mannozzi et al., 2018).

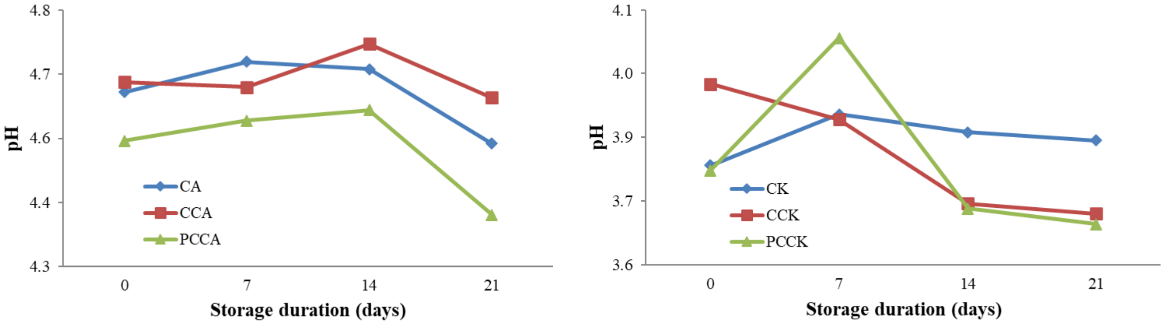


(a) (b)

Figure 1. Dry matter content of apple (a) and kiwifruit samples (b) during 21 days of storage.

pH

The optimal pH for maximum PPO activity ranges from approximately 4 to 7, and this can vary depending on factors such as the fruit part from which the enzyme is extracted, the extraction method used, and the specific substrate involved (Rocha et al., 1998). In many studies, the optimal pH for apple PPO is reported to be between 4.5 and 5.0, while other studies indicate the presence of two separate optimum points, around pH 5.0 and 7.0 (Yoruk & Marshall, 2003). Throughout the 21-day storage period, the pH levels of CA, CCA, and PCCA samples ranged from 4.54 to 4.70, 4.63 to 4.74, and 4.40 to 4.61, respectively as illustrated in Figure 2a. The differences observed in pH values during storage were found to be statistically significant ($p<0.05$). During the storage period, PCCA samples had the lowest pH values, while CCA samples (except on the 7th day) had the highest pH values. That is, in comparison to the control, the use of CS alone as a coating material slightly increased the pH, while the addition of phenolic extracts to the coating formulation resulted in a slight decrease in pH, showing that CS coating in apple slices controlled the pH variations at 8°C. In other words, CCA samples effectively postponed fruit senescence during the storage period in comparison to other samples. This could be attributed to the formation of a semi-permeable CS film on the fruit's surface, which likely altered the internal atmosphere, specifically the inherent CO_2 and O_2 levels, thereby slowing down the ripening process (Abbasi et al., 2009). Previously, Kumar et al. (2021) reported that as fruits and vegetables were stored, their pH typically decreased over time, primarily due to delayed utilization of organic compounds as well as an increase in respiration rate and acidity.



(a) (b)

Figure 2. pH values of apple (a) and kiwifruit samples (b) during 21 days of storage.

Acidity is the primary factor that affects the taste of fruits (Manzoor et al., 2021). As depicted in Figure 2b, the pH levels of CK, CCK, and PCCK samples varied within the ranges of 3.80-3.90, 3.70-4.0, and 3.68-4.05, respectively, during the 21-day storage period. The differences in pH values were found to be statistically significant ($p<0.05$). While the pH value was higher in CCK samples compared to the CK and PCCK on the 0^{th} day of storage, the highest pH level was observed in PCCK samples on day 7. While the pH value of the uncoated samples was the highest at 14^{th} and 21^{st} days, this value was the lowest in PCCK samples. Similarly, Huang et al. (2017) coated Chinese kiwifruits with salicylic acid and/or chitosan and evaluated pH changes over 14 days compared to control samples. According to the findings, the highest pH value was reached in the control samples on Day 6, while the increase in pH in the coated samples was reported to be lower compared to the control sample. Likewise, Manzoor et al. (2021) used different nanoemulsion coating formulations (alginate/ carboxymethylcellulose, vanillin, ascorbic acid) for improving the shelf life of fresh cut kiwi. They reported that at day 7 of storage, the control fruit exhibited the most significant pH increase, reaching 3.90. Moreover, on the 14^{th} and 21^{st} days, the observation of the lowest pH values in PCCK samples was attributed to the inhibition of organic acids' decomposition. This inhibition was believed to occur due to the combined effects of chitosan and phenolic extracts containing LPE and PPE, which exhibit antioxidative and respiration-inhibiting properties (Fozi et al., 2022; Jodhani & Nataraj, 2021).

Weight loss

The loss of weight in vegetables and fruits is a good index of quality degradation, which in turn impacts their marketability (Nair et al., 2018). The act of cutting and peeling fruits such as apples leads to swift alterations in their color and appearance, while skinless fruit slices experience gradual moisture and weight reduction over time. This decrease in weight, which inevitably occurs when the fruit's surface lacks protection, is a factor that detrimentally impacts the product's quality (Chauhan et al., 2011; Cofelice et al., 2019). CA samples demonstrated weight losses of 2.97% at the end of 7 days, 4.54% at the end of 14 days, and 6.64% at the end of 21-days. Meanwhile, CCA samples showed weight increases of 0.52% after 7 days, 2.33% after 14 days, and 6.14% after 21-days. In terms of PCCA samples, their weights increased by 0.44% after 7 days, 2.06% after 14 days, and 4% after 21-days (Table 1).

Table 1. Percent weight loss values of apple and kiwi-fruit slices during 21 days of storage.

Samples	**Weight loss (%)**			
	0^{th} day	**7^{th} day**	**14^{th} day**	**21^{th} day**
CA	$0.00±0.00^{Aa}$	$2.97±1.90^{Ab}$	$4.54±2.01^{Ab}$	$6.64±0.02^{Aa}$
CCA	$0.00±0.00^{Aa}$	$-0.52±0.01^{Ba}$	$-2.33±0.58^{Ba}$	$-6.14±0.09^{Ba}$

PCCA	0.00±0.00^{Aa}	-0.44±0.01^{Ba}	-2.06±0.80^{Bb}	-4.00±0.01^{Bb}
CK	0.00±0.00^{Aa}	2.25±0.20^{Aa}	2.89±0.03^{Aa}	2.93±0.09^{Aa}
CCK	0.00±0.00^{Aa}	-0.92±0.08^{Ba}	-1.88±0.01^{Cb}	-2.12±0.08^{Bb}
PCCK	0.00±0.00^{Aa}	-0.66±0.08^{Ba}	-1.62±0.08^{Ba}	-1.92±0.02^{Bb}

CA: Uncoated apple; CCA: Apple with chitosan coating; PCCA: Apple with chitosan+phenolic extract coating; CK: Uncoated kiwifruit; CCK: Kiwifruit with chitosan coating; PCCK: Kiwifruit with chitosan+phenolic extract coating.

The lowercase letters indicate the statistical difference among samples of the same fruit variety, while the uppercase letters represent the statistical difference during the storage period ($p<0.05$).
s

CK samples experienced weight losses of 2.25% after 7 days, 2.89% after 14 days, and 2.93% after 21-days. The amount of weight loss in the control samples was higher in apple samples compared to kiwi fruits during the storage period. The duration of storage also led to an increased weight loss ratio, as previously reported by Abbasi et al. (2009). The primary reason for the highest weight loss observed in untreated control fruits could be attributed to their elevated rates of respiration and transpiration (Shiri et al., 2013). That is, since the uncoated pericarp lacked a protective barrier, it allowed heat to transfer from the surrounding environment into the fruit slices, resulting in water loss (Lin et al., 2011). On the other hand, CCK samples exhibited weight gains of 0.92% after 7 days, 1.88% after 14 days, and 2.12% after 21-days. PCCK samples showed weight increases of 0.66% after 7 days, 1.62% after 14 days, and 1.92% after 21-days (Table 1). Likewise, it was reported that the incorporation of different compounds into the edible coatings altered their water vapor permeability (Ali et al., 2015; Nair et al., 2018). Additionally, weight gain can occur due to the fact that some coating materials, such as CS, have the ability to absorb water (Dutta et al., 2009). This phenomenon aided in regulating the formation of free water within kiwifruits (Huang et al., 2017). Moreover, Kyriakidou et al. (2021) found that incorporating PPE into CS films decreased their moisture adsorption capacity, particularly in environments with intermediate and high relative humidity values ($a_w>0.4$), likely because of the hydrophobic nature of the extracted phenolics from the pomegranate peel. This led to the absorption of water on the surface of the coated fruits, consequently resulted in weight gain. In a related study, Howard and Griffin (1993) observed no weight loss in minimally processed carrot sticks after 15 days of storage at 2.5°C. This was likely attributed to the high relative humidity inside the package, which slowed down moisture loss and tissue dehydration.

Color attributes

The color of products like apple slices serves as a significant indicator of quality, with brown apple slices being visually undesirable. This discoloration occurs as a result of oxidative reactions involving phenolic compounds catalyzed by polyphenol oxidase, leading to the formation of o-quinones and their subsequent polymerization into various compounds (Lee et al., 2003). Figure 3 provides a summary of the color properties for both coated and uncoated apple and kiwi samples. The $L*$ value represents the brightness level, ranging from 0 to 100 to signify darkness to lightness (Atlar et al., 2024). On the other hand, the $a*$ value measures the intensity of the green-to-red color spectrum, where a higher positive value indicates a stronger presence of red (Yavuz et al., 2022). Similarly, the $b*$ value indicates the intensity of the blue-to-yellow color spectrum, with a higher positive value indicating a greater presence of yellow (Demirkan et al., 2024).

CA samples exhibited a range of $L*$ values from 64.6 to 67.6 during the storage period. A decrease in lightness was observed for CA samples over time, except for the 7th and 14th days when no significant changes in $L*$ values were noticed. Among the CCA samples, the highest $L*$ value of 73.2 was recorded on Day 0, while the lowest $L*$ value of 47.5 was observed on Day 21. Lightness increased as the storage period advanced for CCA samples. The L^* values for PCCA samples showed an increase with the progression of the storage period, ranging from 59.6 to 69.9. Hence, the color of PCCA samples became lighter as the storage duration increased. According to Lin et al. (2011), respiration generated bio-heat, leading to an increase in the temperature of the fruit group, which in turn accelerated water loss and browning.

The a^* values of samples named CA (8.7-11.7) decreased until the 14th day, and then slightly increased on the 21st day. Regarding the samples CCA (8.3-16.5), there was a significant increase in redness until the 7th day, reaching its highest level. The redness slightly decreased on the 14th day and further decreased on the 21st day. Among the apple samples, the lowest redness on the 0th day was measured in the CCA samples, while the highest a^* value at the end of storage was also observed in the same samples. For the PCCA (8.2-13.6) samples, the highest level of redness was measured on the 0th day, and the lowest a^* values were observed on the 7th day. Subsequently, although the redness did not reach the initial value (0th day) during the other storage periods (14th and 21st days), it increased to some extent. In earlier findings, it was stated that lower L^* values and higher a^* values were indicative of increased browning (Lee et al., 2003). The results of the study showed that the least pronounced browning occurred in PCCA, while the darkest coloration was observed in CCA on different storage days. In other words, the application of phenolic extracts inhibited browning due to their reducing power. Furthermore, while CS alone was insufficient in preventing apple browning, its combination with phenolic compounds had synergistic effects in inhibiting browning.

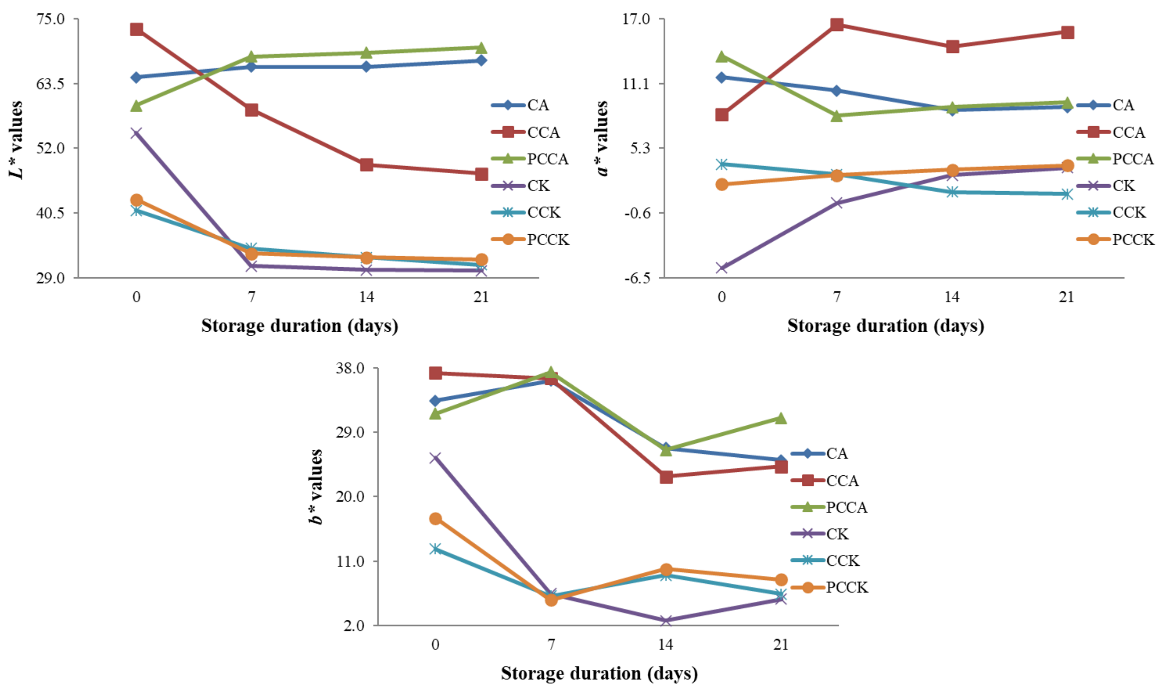


Figure 3. Color properties of apple and kiwifruit slices during 21 days of storage.

Regarding the b* values of CA samples (25.2-36.2) (Figure 3) there was an increase in yellowness until the 7th day, followed by a decrease in yellowness throughout the rest of the storage period. In the case of CCA samples (22.8-37.3) (Figure 3), there was a significant decrease in yellowness until the 14th day, but a slight increase in yellowness was observed towards the end of storage (21st day). PCCA samples (26.5-37.4) (Figure 3), on the other hand, exhibited a different trend in the measured *b** values compared to the other apple samples, showing fluctuations throughout the storage period. However, at the end of storage, the *b** values were nearly the same as the initial values. The results indicated that CS coating initially increased the level of yellowness, but after 21 days, the samples with the lowest yellowness were still found in CCA.

Similar to CCA samples, the *L** values measured during the storage period for CK (30.24-54.7), CCK (31.3-41.0), and PCCK (32.3-42.9) samples followed a comparable trend, indicating an increase in darkness compared to the initial value. The darkening of kiwifruit slices during storage occurred due to the emergence of translucent symptoms rather than enzymatic browning. This was attributed to the fact that kiwifruits had low levels of tannin and polyphenol oxidase (Chiabrando et al., 2018). Furthermore, Park & Luh (1985) reported that the acidic nature of kiwifruit also suppressed PPO activity. Except for Day 0, the coated kiwifruit slices had a brighter color compared to the uncoated kiwifruit slices on the other storage days.

Regarding the CK samples, *a** values ranged from -5.6 to 3.5. On the 0th day of storage, greenness was dominant, but by the 7th day, the color shifted towards red, and this trend continued in the subsequent storage days. In contrast to CK and PCK samples, the CCK samples exhibited a decrease in *a** values (ranging from 1.1 to 3.8) with an increase in storage time. On the other hand, the PCK samples showed an increase in *a** values from 2.0 to 3.7 as the storage duration increased.

The *b** values were determined for CK samples (2.7-25.4), CCK samples (6.1-12.7), and PCCK samples (5.6-17.0). The highest yellowness values were measured on the 0th day, but by the 7th day, there was a sharp decrease in yellowness. Fluctuations continued in the following storage days. However, compared to the initial values, the storage duration resulted in a significant decrease in yellowness for the kiwi samples.

Visual examination of fungal decay

Freshly cut fruits serve as ideal environments for microbial proliferation due to their expansive cut surface area, allowing water and nutrients to seep from injured tissues, thus rendering them highly prone to decay by microorganisms (Manzoor et al., 2021). In the present study, no visual mold formation and growth were observed in any of the non-coated and coated apple and kiwifruit slices. CS is extensively documented for its potent and bioactive fungicidal properties; numerous studies have provided evidence of the antifungal effectiveness of both natural and fungal-derived CS against a diverse range of pathogenic fungi (Tayel et al., 2010; Tayel et al., 2016). In addition to its antimicrobial properties, chitosan coating also inhibits polyphenol oxidase activity, thus preventing enzymatic deterioration of the fruit and reducing both respiration rate and weight loss (Kaya et al., 2016). Moreover, PPE was found to contain a significant number of phenolic compounds, particularly punicalagins, which are classified as ellagitannins and have been demonstrated to possess antifungal properties (Nicosia et al., 2016). LPE contains flavonoids, which belong to a group of secondary metabolites known for their potent antioxidant properties (Jodhani & Nataraj, 2021).

Sensory properties

The taste scores of both coated and uncoated apple samples ranged from 2 to 5 as shown in Table 2. Accordingly, the highest taste scores were obtained on day 0. However, with an increase in storage time, there was a significant decrease in these scores. After 21 days of storage, no significant difference was observed between the tested samples ($p>0.05$), while the PCCA samples significantly obtained the highest taste score (3.0). As expected, sliced apple samples obtained the highest odor score on day 0, while these scores were at their lowest level on day 21. The highest odor scores after 21 days of storage were observed in PCCA samples (3.4). In terms of texture scores of apple slices, the scores for CA ranged from 3.60 to 4.40, and they decreased with the increase in storage duration. However, this decrease was not statistically significant ($p>0.05$). The texture evaluation results of CCA samples were found to be 2.80 on days 0 and 7, and 3.00 on days 14 and 21. However, the slight increase was also not statistically significant ($p>0.05$). On the other hand, PCCA samples slightly decreased from 4.20 to 3.40 on day 7 and then remained unchanged during the storage period. This slight decrease can be due to acid hydrolysis of the pectic acid, which resulted in increased softness (Lee et al., 2003). For apple slice samples, the application of CS or CS+phenolic extracts did not have any negative effect on taste, or texture throughout the 3-week storage period. Our findings align with those of De Leon-Zapata et al. (2015), who similarly observed that the application of candelilla wax coating infused with fermented tarbush extract on apples did not result in any unfavorable alterations in their appearance and taste over an 8-week storage period.

Table 2. Sensory properties of apple and kiwifruit samples during 21 days of storage.

Sensory properties	**Samples**	**Sensory scores**			
		0th day	**7th day**	**14th day**	**21th day**
Taste	CA	5.00 ± 0.00^{Aa}	4.20 ± 0.84^{Aa}	2.80 ± 0.84^{Ba}	2.00 ± 0.71^{Ca}
	CCA	4.40 ± 0.89^{Aa}	4.20 ± 0.84^{Aa}	3.20 ± 0.84^{Ba}	2.40 ± 0.55^{Ca}
	PCCA	4.20 ± 1.30^{Aa}	3.80 ± 0.84^{Aa}	3.60 ± 0.55^{Ba}	3.00 ± 1.00^{Ca}
	CK	4.00 ± 1.00^{Aa}	3.80 ± 1.10^{Aa}	3.80 ± 1.10^{Aa}	2.60 ± 0.55^{Ba}
	CCK	4.60 ± 0.55^{Aa}	4.40 ± 0.89^{Aa}	4.00 ± 1.00^{Aa}	3.20 ± 1.10^{Ba}
	PCCK	4.60 ± 0.89^{Aa}	4.20 ± 0.84^{Aa}	3.40 ± 1.34^{Aa}	2.80 ± 0.84^{Ba}
Odor	CA	4.60 ± 0.55^{Ab}	4.00 ± 1.00^{ABb}	3.00 ± 0.71^{Bb}	1.80 ± 0.84^{Cb}
	CCA	3.40 ± 1.52^{Ab}	3.00 ± 0.71^{ABb}	2.80 ± 0.84^{Bb}	2.20 ± 0.84^{Cb}
	PCCA	4.20 ± 0.84^{Aa}	4.40 ± 0.55^{ABa}	4.20 ± 0.45^{Ba}	3.40 ± 0.55^{Ca}
	CK	4.40 ± 0.89^{Aa}	4.40 ± 0.89^{ABa}	3.20 ± 0.84^{BCa}	2.60 ± 0.55^{Ca}
	CCK	4.40 ± 0.55^{Aa}	3.40 ± 1.14^{ABa}	3.80 ± 0.84^{BCa}	3.20 ± 0.84^{Ca}
	PCCK	4.60 ± 0.55^{Aa}	4.20 ± 0.45^{ABa}	4.00 ± 0.00^{BCa}	3.60 ± 0.55^{Ca}
Texture	CA	4.40 ± 0.55^{Aa}	3.80 ± 0.84^{Aa}	3.80 ± 0.84^{Aa}	3.60 ± 0.55^{Aa}
	CCA	2.80 ± 0.84^{Ab}	2.80 ± 0.84^{Ab}	3.00 ± 1.00^{Ab}	3.00 ± 1.00^{Ab}
	PCCA	4.20 ± 0.84^{Aa}	3.40 ± 0.55^{Aa}	3.40 ± 0.55^{Aa}	3.40 ± 0.55^{Aa}
	CK	4.80 ± 0.45^{Aa}	4.20 ± 0.84^{Aa}	4.40 ± 0.55^{Aa}	4.20 ± 0.45^{Aa}
	CCK	4.40 ± 0.89^{Aa}	4.40 ± 0.89^{Aa}	4.20 ± 0.84^{Aa}	4.20 ± 0.84^{Aa}
	PCCK	4.60 ± 0.55^{Aa}	4.60 ± 0.55^{Aa}	4.40 ± 0.55^{Aa}	4.00 ± 1.00^{Aa}

*The lowercase letters indicate the statistical difference among samples of the same fruit variety, while the uppercase letters represent the statistical difference during storage period ($p<0.05$).

The taste scores of coated and uncoated kiwi samples ranged from 2.60 to 4.60 (Table 2). There was not much variation in taste scores for kiwi samples between 0 and 14 days, but after 21-days of storage, the lowest scores were obtained. However, no significant difference was found among tested kiwi samples after 21-days of storage ($p<0.05$). Possible variations in acidity, pH, and sugar/acid ratio of fruit samples could be contributing factors to these fluctuations in taste scores (Abbasi et al., 2009).

Regarding the odor characteristics of kiwifruit slices, similar to apple samples, the highest ratings were determined on day 0. These values decreased until the end of the storage day. The highest odor scores after the end of storage were obtained by CCK and PCCK samples. However, no statistical difference was found between tested kiwifruit samples stored for 21days($p>0.05$).

Firmness in fruits and vegetables is consistently indicative of freshness and quality, and the loss of texture contributes to fruit softening, resulting in decreased consumer demand (Nair et al., 2018). For kiwifruit samples, the highest texture score level was observed on day 0. There were slight fluctuations in the texture scores of CK during the storage period; however, these fluctuations were statistically non-significant ($p>0.05$). The texture evaluation results of CCK samples were found to be 4.40 on days 0 and 7, and 4.20 on days 14 and 21, with a statistically insignificant decrease ($p>0.05$). For PCCK samples, texture scores remained unchanged on days 0 and 7, while an increase in storage time led to a decrease in these scores; however, this decrease was not statistically significant ($p>0.05$). The combination of phenolic extracts and CS led to retardation of softening in kiwifruit slices until 14 days of storage. This phenomenon can be attributed to the restricted microbial load, as well as decreased respiration rate and moisture loss (Nair et al., 2018).

Conclusion

The findings showed that the coating process had different effects on the dry matter content and pH value of the apples during storage. Furthermore, based on sensory analysis, apples coated with CS+phenolic extract were superior in terms of aroma and odor compared to other, suggesting positive effects during storage. However, CS+phenolic extract coated apple slices showed increased browning compared to CS-coated and uncoated slices. In the case of kiwi fruit, the coated samples showed a different effect in terms of dry matter content, pH and weight loss compared to the control ones. During storage, all kiwifruit samples exhibited a slight darkening and less yellowness in color attributes. Browning was most pronounced in samples treated with phenolic extract+CS and least in CS-coated kiwifruit. No visual observation of fungal decay was detected in any of the apple and kiwifruit slices, both coated and non-coated. In terms of taste, CS-coated kiwifruits and CS+phenolic extracts-coated kiwifruits received the highest preference, while in terms of odor and texture, CS+phenolic extracts-coated kiwifruits obtained the highest liking. In conclusion, the application of CS+phenolic extract as active coatings on a large scale are viable to preserve some quality attributes of apple and kiwifruit slices.

Acknowledgments

This work was supported by The Scientific and Technological Research Council of Türkiye (TUBITAK). Grant/ Award Number: 1919B012003845

References

Abbasi, N. A., Iqbal, Z., Maqbool, M., & Hafiz, I. A. (2009). Postharvest quality of mango (Mangifera indica L.) fruit as affected by chitosan coating. *Pakistan Journal of Botany*, *41*(1), 343-357.

Ali, A., Noh, N. M., & Mustafa, M. A. (2015). Antimicrobial activity of chitosan enriched with lemongrass oil against anthracnose of bell pepper. *Food packaging and shelf life*, *3*, 56-61.

AOAC, (1994), Official Methods of Analysis, Association of Official Analytical Chemists, 1111 North 19th Street, Suite 20, 16th Edi. Arlington, Virginia USA (1994), p. 22209

AOAC International, (2002), Official methods of analysis (OMA) of AOAC International, 17th Edition, USA, Method number: 920.15, Available at:http://www.eoma.aoac.org/

Atlar, G. C., Kutlu, G., & Tornuk, F. (2024). Design and characterization of chitosan-based films incorporated with summer savory (Satureja hortensis L.) essential oil for active packaging. *International Journal of Biological Macromolecules*, *254*, 127732.

Badawy, M. E., Rabea, E. I., AM El-Nouby, M., Ismail, R. I., & Taktak, N. E. (2017). Strawberry shelf life, composition, and enzymes activity in response to edible chitosan coatings. *International Journal of Fruit Science*, *17*(2), 117-136.

Benhabiles, M. S., Drouiche, N., Lounici, H., Pauss, A., & Mameri, N. (2013). Effect of shrimp chitosan coatings as affected by chitosan extraction processes on postharvest quality of strawberry. *Journal of Food*

Measurement and Characterization, *7*, 215-221.

Chauhan, O. P., Raju, P. S., Singh, A., & Bawa, A. S. (2011). Shellac and aloe-gel-based surface coatings for maintaining keeping quality of apple slices. *Food chemistry*, *126*(3), 961-966.

Chiabrando, V., Peano, C., & Giacalone, G. (2018). Influence of hot water treatments on postharvest physicochemical characteristics of Hayward and Jintao kiwifruit slices. *Journal of Food Processing and Preservation, 42*(3), e13563.

Cofelice, M., Lopez, F., & Cuomo, F. (2019). Quality control of fresh-cut apples after coating application. *Foods*, *8*(6), 189.

De Corato, U. (2019). Improving the shelf-life and quality of fresh and minimally processed fruits and vegetables for a modern food industry: A comprehensive critical review from the traditional technologies into the most promising advancements. *Critical Reviews in Food Science and Nutrition, 1–36.*

De Leon-Zapata, M. A., Saenz-Galindo, A., Rojas-Molina, R., Rodríguez-Herrera, R., Jasso-Cantu, D., & Aguilar, C. N. (2015). Edible candelilla wax coating with fermented extract of tarbush improves the shelf life and quality of apples. *Food packaging and shelf life, 3,* 70-75.

Demirkan, E. N., Akyürek, Ş. N., Bayraktar, D., Kutlu, G., & Törnük, F. (2024). Potential use of hazelnut (Corylus avellana L.) shell powder in muffin production by partial substitution of wheat flour: Color, bioactive, textural, and sensory properties. *European Food Science and Engineering, 5*(1), 1-7.

Dutta, P. K., Tripathi, S., Mehrotra, G. K., & Dutta, J. (2009). Perspectives for chitosan based antimicrobial films in food applications. *Food chemistry, 114*(4), 1173-1182.

Feyzioglu, G. C., & Tornuk, F. (2016). Development of chitosan nanoparticles loaded with summer savory (Satureja hortensis L.) essential oil for antimicrobial and antioxidant delivery applications. *LWT*, *70*, 104-110.

Fozi, V., Hosseinifarahi, M., Bagheri, F., & Amiri, A. (2022). Extending shelf life of mandarin fruit using pomegranate peel extract. *International Journal of Horticultural Science and Technology, 9*(1), 15-24.

Garrido Assis, O. B., & de Britto, D. (2011). Evaluation of the antifungal properties of chitosan coating on cut apples using a non-invasive image analysis technique. *Polymer International*, *60*(6), 932-936.

Gomes, A. C. A., da Costa Lima, M., de Oliveira, K. Á. R., dos Santos Lima, M., Magnani, M., Câmara, M. P. S., & de Souza, E. L. (2020). Coatings with chitosan and phenolic-rich extract from acerola (Malpighia emarginata DC) or jabuticaba (Plinia jaboticaba (Vell.) Berg) processing by-product to control rot caused by Lasiodiplodia spp. in papaya (Carica papaya L.) fruit. *International Journal of Food Microbiology*, *331*, 108694.

Guroo, I., Gull, A., Wani, S. M., Wani, S. A., Al-Huqail, A. A., & Alhaji, J. H. (2021). Influence of different types of polysaccharide-based coatings on the storage stability of fresh-cut kiwi fruit: Assessing the physicochemical, antioxidant and phytochemical properties. *Foods*, *10*(11), 2806.

Han, C., Lederer, C., McDaniel, M., & Zhao, Y. (2006). Sensory Evaluation of Fresh Strawberries (Fragaria ananassa) Coated with Chitosan-based Edible Coatings. *Journal of Food Science, 70*(3), S172–S178.

Howard, L. R., & Griffin, L. E. (1993). Lignin Formation and Surface Discoloration of Minimally Processed Carrot Sticks.

Journal of Food Science, 58(5), 1065–1067.

Huang, Z., Li, J., Zhang, J., Gao, Y., & Hui, G. (2017). Physicochemical properties enhancement of Chinese kiwi fruit (Actinidia chinensis Planch) via chitosan coating enriched with salicylic acid treatment. *Journal of Food Measurement and Characterization*, *11*, 184-191.

Jodhani, K. A., & Nataraj, M. (2021). Synergistic effect of Aloe gel (Aloe vera L.) and Lemon (Citrus Limon L.) peel extract edible coating on shelf life and quality of banana (Musa spp.). *Journal of Food Measurement and Characterization*, *15*, 2318-2328.

Kaya, M., Česonienė, L., Daubaras, R., Leskauskaitė, D., & Zabulionė, D. (2016). Chitosan coating of red kiwifruit (Actinidia melanandra) for extending of the shelf life. *International Journal of Biological Macromolecules*, *85*, 355-360.

Kumar, N., Petkoska, A. T., AL-Hilifi, S. A., & Fawole, O. A. (2021). Effect of chitosan–pullulan composite edible coating functionalized with pomegranate peel extract on the shelf life of mango (Mangifera indica). *Coatings*, *11*(7), 764.

Kutlu, G. (2021). *Ruşeym yağının nanoenkapsülasyonu ve gıdalarda kullanım olanaklarının artırılması* (Doctoral dissertation).

Kutlu, G., Yılmaz, S. & Karabulut, E. A. (2024). Development of a new vegan muffin formulation: Assessing its quality and sensory characteristics. *European Food Science and Engineering*, *5* (1), 26-34.

Kyriakidou, A., Makris, D. P., Lazaridou, A., Biliaderis, C. G., & Mourtzinos, I. (2021). Physical properties of chitosan films containing pomegranate peel extracts obtained by deep eutectic solvents. *Foods, 10*(6), 1262

Lee, J. Y., Park, H. J., Lee, C. Y., & Choi, W. Y. (2003). Extending shelf-life of minimally processed apples with edible coatings and antibrowning agents. *LWT-Food Science and Technology*, *36*(3), 323-329.

Lin, B., Du, Y., Liang, X., Wang, X., Wang, X., & Yang, J. (2011). Effect of chitosan coating on respiratory behavior and quality of stored litchi under ambient temperature. *Journal of Food Engineering*, *102*(1), 94-99.

Liu, X., Ren, J., Zhu, Y., Han, W., Xuan, H., & Ge, L. (2016). The preservation effect of ascorbic acid and calcium chloride modified chitosan coating on fresh-cut apples at room temperature. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *502*, 102-106.

Mannozzi, C., Cecchini, J. P., Tylewicz, U., Siroli, L., Patrignani, F., Lanciotti, R., Racculi, P., Dalla Rosa, M. & Romani, S. (2017). Study on the efficacy of edible coatings on quality of blueberry fruits during shelf-life. *LWT-Food Science and Technology*, *85*, 440-444.

Mannozzi, C., Tylewicz, U., Chinnici, F., Siroli, L., Rocculi, P., Dalla Rosa, M., & Romani, S. (2018). Effects of chitosan based coatings enriched with procyanidin by-product on quality of fresh blueberries during storage. *Food Chemistry*, *251,* 18–24.

Mannozzi, C., Glicerina, V., Tylewicz, U., Castagnini, J. M., Canali, G., Dalla Rosa, M., & Romani, S. (2021). Influence of two different coating application methods on the maintenance of the nutritional quality of fresh-cut melon during storage. *Applied Sciences*, *11*(18), 8510.

Manzoor, S., Gull, A., Wani, S. M., Ganaie, T. A., Masoodi, F. A., Bashir, K., Malik A.R. & Dar, B. N. (2021). Improving the shelf life of fresh cut kiwi using nanoemulsion coatings with antioxidant and antimicrobial agents. *Food Bioscience, 41*, 101015.

Nair, M. S., Saxena, A., & Kaur, C. (2018). Characterization and antifungal activity of pomegranate peel extract and its use in polysaccharide-based edible coatings to extend the shelf-life of capsicum (Capsicum annuum L.). *Food and bioprocess technology*, *11*, 1317-1327.

Nicosia, M. G. L. D., Pangallo, S., Raphael, G., Romeo, F. V., Strano, M. C., Rapisarda, P., Droby, S., & Schena, L. (2016). Control of postharvest fungal rots on citrus fruit and sweet cherries using a pomegranate peel extract. *Postharvest Biology and Technology*, *114*, 54–61.

Park, E. Y., & Luh, B. S. (1985). Polyphenol Qxidase of Kiwifruit. *Journal of Food Science, 50*(3), 678–684.

Qi, H., Hu, W., Jiang, A., Tian, M., & Li, Y. (2011). Extending shelf-life of fresh-cut 'Fuji'apples with chitosan-coatings. *Innovative Food Science & Emerging Technologies, 12*(1), 62-66.

Rocha, A. M., Cano, M. P., Galeazzi, M. A., & Morais, A. M. (1998). Characterisation of 'Starking'apple polyphenoloxidase. *Journal of the Science of Food and Agriculture*, *77*(4), 527-534.

Shiri, M. A., Bakhshi, D., Ghasemnezhad, M., Dadi, M., Papachatzis, A., & Kalorizou, H. (2013). Chitosan coating improves the shelf life and postharvest quality of table grape (Vitis vinifera) cultivar Shahroudi. *Turkish journal of agriculture and forestry*, *37*(2), 148-156.

Singh, B., Singh, J. P., Kaur, A., & Singh, N. (2019). Antimicrobial potential of pomegranate peel: A review. *International Journal of Food Science & Technology, 54*(4), 959-965.

Tayel, A. A., Moussa, S., Opwis, K., Knittel, D., Schollmeyer, E., & Nickisch-Hartfiel, A. (2010). Inhibition of microbial pathogens by fungal chitosan. *International journal of biological macromolecules*, *47*(1), 10-14.

Tayel, A. A., Moussa, S. H., Salem, M. F., Mazrou, K. E., & El-Tras, W. F. (2016). Control of citrus molds using bioactive coatings incorporated with fungal chitosan/plant extracts composite. *Journal of the Science of Food and Agriculture*, *96*(4), 1306-1312.

Yavuz, Z., Kutlu, G., & Tornuk, F. (2022). Incorporation of oleaster (Elaeagnus angustifolia L.) flour into white bread as a source of dietary fibers. *Journal of Food Processing and Preservation, 46*(11), e17050.

Yoruk, R., & Marshall, M. R. (2003). Physicochemical properties and function of plant polyphenol oxidase: A review. *Journal of Food Biochemistry, 27*(5), 361–422.

Xi, W., Lu, J., Qun, J., & Jiao, B. (2017). Characterization of phenolic profile and antioxidant capacity of different fruit part from lemon (Citrus limon Burm.) cultivars. *Journal of food science and technology*, *54*, 1108-1118.