



Sustainable Apple Coating by Biodegradable Gelatin Film Containing Oregano (*Origanum vulgare* L.) Essential Oil

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ABSTRACT

Background: Apples produced annually are lost due to post-harvest spoilage. On the other hand, the demand for environmentally friendly packaging materials has increased sharply due to environmental concerns regarding the use of petroleum polymers. One of the best ways to overcome these problems is to include essential oils in the packaging film.

Methods: Present study aimed to investigate the effect of biodegradable film based on Gelatin containing oregano (*Origanum vulgare* L.) essential oil (with concentrations 5, 10 and 20% w/w) as an active packaging to increase the post-harvest life of Apple fruit. The effect of the films on maintaining the quality properties of apple during 15 days of storage at 4°C was investigated and the number of qualitative changes of the samples (weight, firmness, soluble solids, pH and microbial contamination).

Result: During this period were evaluated. This study showed that the quality of the samples decreased during the storage period; however, the decrease in the packaged samples was significantly less than in the unpackaged samples. Also, adding essential oil to the polymer film resulted in better preservation of the quality properties of apple and with increasing the concentration of oregano (*Origanum vulgare* L.) essential oil, the decrease in the quality of strawberry samples was slower. Therefore, it seems that using biodegradable film, Gelatin containing oregano (*Origanum vulgare* L.) essential oil can be an active packaging; it greatly reduces post-harvest waste of apples.

Key words: Green environmental impact, Non-toxic ingredients, Reduction, Sustainable agriculture.

INTRODUCTION

Our country faces a serious problem with post-harvest waste of agricultural products, which also lowers its export and marketing value (Rodrigues *et al.*, 2025). A critical stage in this process is examining the shelf life and determining how it can be extended (Calligaris and Manzocco, 2012). Apple's quality declines during post-harvest life primarily due to its high physiological activity and sensitivity to fungal rots, such as gray mold. This product is also sensitive to weight loss and water loss. In general, Apples are vulnerable to mechanical damage because of their soft texture and their lack of a protective skin (Mikus and Galus, 2025). Research has been conducted to preserve and extend the shelf life of this fruit and most of the efforts have focused on improving its quality after harvest (Ninama *et al.*, 2024). Among the most common methods of extending Apple's post-harvest life are cold storage, modified or controlled atmosphere. In spite of this, both scientific research and practical experience show that these methods are associated with problems and shortcomings. A low cold storage temperature alone cannot prevent fungal disease in apple; a controlled or modified atmosphere packaging environment with high carbon dioxide concentrations decreases the aromatic compounds in the fruit, the antioxidant capacity and the total anthocyanin content (Butkeviciute *et al.*, 2022). Therefore, attention should be paid to new solutions to increase the post-harvest life of apple while maintaining quality and value. However, the use of petroleum-based polymers has raised environmental concerns that have made environmentally

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friendly packaging materials more sought after. Due to their biodegradability, biopolymer-based packaging materials have a high potential for replacing petroleum-based plastics. Biodegradable films with various components such as lipids, polysaccharides and proteins have been developed; among them, Gelatin can be mentioned. This polymer is a hydrophobic protein found in corn endosperm and is a by-product of corn wet milling. This polymer is also known as prolamin, which has high thermoplastic properties and exhibits very good barrier properties against gas permeability, but it has low resistance to water vapor permeability. Another problem with Gelatin is that the film obtained from this polymer is brittle (Zhang *et al.*, 2023). Therefore, despite the environmental advantages of Gelatin,

its practical application is not possible due to its undesirable mechanical and barrier properties. To overcome these limitations, crosslinking is a common and highly effective method to enhance the mechanical, barrier and water resistance properties of biodegradable films (De Almeida *et al.*, 2010). Although synthetic crosslinking agents such as glutaraldehyde and glyoxal are widely used, inflammatory problems remain a concern (Hazarika *et al.*, 2023). Therefore, it seems necessary to replace these materials with a biodegradable crosslinking agent. Phenolic compounds present in essential oils and plant extracts can be used for this purpose. Oxidation of phenolic compounds leads to the production of quinones that can react with the side chains of polymer groups through covalent or hydrogen bonding; intermolecular interactions lead to cross-linking between the chains and consequently improve the film properties (Makishi *et al.*, 2013). In addition, essential oils and plant extracts, due to their effect on the vapor phase, also provide the possibility of controlling post-harvest diseases of agricultural and food crops. The use of these films was associated with improved preservation of the physicochemical properties of the samples during the storage period; Therefore, with only one third of the concentration of the total essential oil compounds required for the films, the film containing carvacrol: thymol provides effective inhibition of *B. cinerea* without significant changes in the organoleptic properties of apple. However, it seems that the potential of Gelatin film containing oregano essential oil as an active biodegradable and antimicrobial packaging film in the preservation of Apples products has not been evaluated so far, this study aimed to investigate the effect of this active and biodegradable film on some quality properties of apples during the storage period.

MATERIALS AND METHODS

This study was conducted in the Department of Biology at Mustansiriyah University during the period from March to Jun 2025. Oregano (*Origanum vulgare* L.) Essential Oil: Essential Oil was provided to us by Tabib Daru Company. As determined by gas chromatography-mass spectrometry (GC-MS) analysis (Tahmasebi *et al.*, 2020). Gelatin was purchased from Himedia (Mumbai, India). The gelatin coatings [5% and 10% (w/v)] were prepared by soluble 5 and 10 grams of gelatin powder in 100 mL of distilled water and stirring continuously for 30 minutes at 70°C (Jukic *et al.*, 2007). In addition to the magnetic stirring, glycerol monostearate (0.75%) was added as a plasticizer and the solution was subsequently cooled to 40 degrees Celsius. In the next step, essential oils were added to the film solution at varying concentrations while stirring for 15 minutes. In the next step, essential oils were added to the film solution at varying concentrations and the mixture was stirred for 15 minutes. With a syringe, the solution was poured into a bag and the air in the bottle was removed. After 24 hours, the bag was placed in a 35°C oven. To

prepare the solution, it was spread into plastic bags and baked for 24 hours.

Fruit collecting and coating

During the experiments, Apple fruits collected from local farms without pesticides, with uniform shape and color, no signs of mechanical damage or fungal decay and washed with distilled water were selected and packaged. After drying, each treatment in this experiment consisted of six Apples weighing approximately 100 grams, which were packaged according to the method used by Do Lago *et al.* (2023). For the protection of the samples from physical contact, all fruits were placed in a polyethylene terephthalate (PET) container divided into four compartments. Using the lid closed, a hole with a diameter of 100 mm was made and a circular piece of film was placed on the lid and sealed with methyl alpha-cyanoacrylate to create a semi-permeable and bioactive packaging. In the beginning, fifth, tenth and fifteenth days of storage, samples were evaluated physically and chemically as follows.

Physical and chemical tests

Physical properties

Weight loss

Weight loss was determined using a digital balance in three repetitions at the beginning of the test and during the storage period and the percentage loss was calculated using the following formula:

$$\text{Weight loss (\%)} = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \times 100$$

Firmness (Kg/cm²)

To conduct this test, we utilized a fruit firmness tester (STEP SYSTEM, Germany) and a steel rod with a standard diameter of 8 mm. The penetration test was performed in the central part of the fruit at 4 points with equal distances on the fruit periphery (Valero *et al.*, 2007). The firmness, recorded at 13 kg/cm², was assessed on each side of the fruit's equatorial region and expressed in kg/cm².

Investigation of chemical properties

Each treatment in each storage period was extracted, mixed and the chemical properties were measured three times, as follows:

Total Soluble Solids (°Brix)

As part of the measurement, drops of fruit juice were poured onto the glass plate of the optical refractometer (0-32 °Brix). and the amount of soluble solids was calculated as a percentage.

pH

In order to measure the pH of fruit juice, a digital pH meter (Metrohm 827) was used at ambient temperature. A certain amount of fruit juice was poured into a beaker and the pH value was measured by placing the electrode in the fruit juice (Ding *et al.*, 2019).

Statistical analysis

In evaluating how the type, concentration and storage duration of essential oils impact product quality, a factorial experiment was conducted using a completely randomized design with at least three repetitions. The collected data were analyzed using SPSS statistical software and Duncan's multiple range test was applied to compare the means, ensuring an acceptable error margin of 5% ($P < 0.05$).

RESULTS AND DISCUSSION

GC-MS analysis of oregano (*Origanum vulgare* L.) essential oil

More than 25 different active compounds (Fig 1). The constituents detected at the highest amounts were carvacrol (62.0%), thymol (15.1%), cterpinene (4.2%). Other constituents, such as linalool (2.1%), myrcene (1.14%) and a variety of other compounds, were detected in low amounts, all below 1%.

Weight loss

Control treatment without coating with Gelatin and essential oil showed a maximum loss of 3.5 % at 15 days of storage for apples. Among all the concentrations, the Gelatin+20% coating showed least reduction in weight loss to 0.5% at 15 days of storage based on the results presented in (Table 1), the analysis of variance of the data showed that the effect of

essential oil concentration, storage time and the interaction effects of these traits on product weight loss was significant at the 5% probability level. Based on the results the weight of the samples decreased in all treatments during the storage period. Among the different packaging types, the lowest weight loss trend during the storage period was observed for samples packaged with control film (Mohanapriya *et al.*, 2024). However, by adding essential oil concentration to the Gelatin film, a greater weight loss was observed in the packaged samples. This phenomenon can be attributed to the increased permeability of the film to water vapor due to the presence of essential oil (Maqbool *et al.*, 2011). Similar results have been reported by other researchers regarding mango packaging with PVA film containing TiO₂ nanoparticles and bergamot essential oil (Chi *et al.*, 2019) and banana with film containing clove essential oil (De Figueiredo Sousa *et al.*, 2019).

Firmness

Essential oil concentration, storage time and the interaction effect of these two treatments on Apples firmness were significant at the 5% probability level. As shown in (Table 2), the firmness of the samples decreases during the storage period. With increasing essential oil concentration, the firmness decreases with a gentler slope. Firmness decreases during fruit ripening and storage due

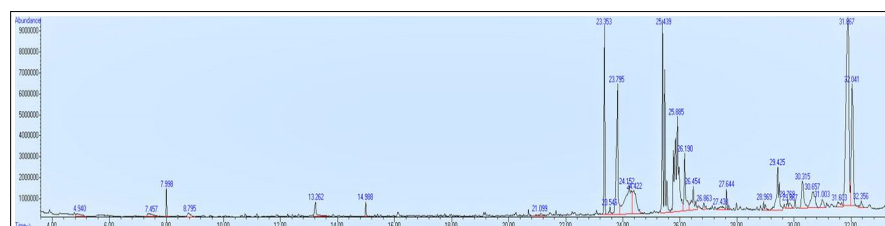


Fig 1: The detection of the active compounds of oregano (*Origanum vulgare* L.) Essential Oil by the GC-MS technology.

Table 1: Effect of different concentrations of Gelatin containing oregano (*Origanum vulgare* L.) essential oil on loss in weight (%) of apples at room temperature storage period.

Loss in weight	Storage period		
	5 th day	10 th day	15 th day
control	1.00±0.9b	1.61±0.1b	3.5±0.3a
Gelatin+5%	0.98±0.1c	1.09±0.1b	2.5±0.04b
Gelatin+10%	0.91±0.2c	1.07±0.2b	2.4±0.04b
Gelatin+20%	0.3±0.3c	0.5±0.8c	0.5±0.07c

Different litters mean significant differences at $p < 0.05$.

Table 2: Effect of different concentrations of Gelatin containing oregano (*Origanum vulgare* L.) essential oil on the fruit firmness of apples.

Fruit firmness (Kg/cm ²)	Storage period		
	5 th day	10 th day	15 th day
control	18.31±0.2d	17.9±0.1c	17.2±0.8c
Gelatin+5%	18.2±0.8	17.5±0.2d	16.98±0.6b
Gelatin+10%	17.6±0.2c	16.3±0.2b	16.23±0.2b
Gelatin+20%	18.2±0.2d	17.5±0.1c	15.85±0.7a

Different litters mean significant differences at $p < 0.05$.

to the destruction of the parenchyma cell wall (Su *et al.*, 2022). In addition, firmness is affected by the strength of the cell wall. Cell-cell contact and turgor are 1 cell (Toivonen and Brummell, 2008). Since the spread of fungal infection in the fruit causes cell wall destruction and death of fruit cells (Ding *et al.*, 2019). By increasing the concentration of essential oil in the packaging film, the growth rate of pathogenic agents and consequently the stiffness decreases at a slower rate. On the other hand, Gelatin and other biopolymers act as a selective barrier for CO₂ and O₂ and improve the atmosphere inside the package, reduce the respiration rate and consequently reduce the physiological deterioration of the fruit (Karnwal *et al.*, 2025).

Soluble solids (SSC)

The results of the analysis of variance of the data (Table 3) showed that the effect of essential oil concentration, storage time at the 5% probability level and their interaction effect at the 5% probability level have a significant effect on soluble solids. Based on the results of the comparison of the means with increasing storage time, the SSC level first increased and then decreased. Also, with increasing the concentration of essential oil in the packaging film, the SSC level increased. This increasing trend at the beginning of the storage time and then the decrease in SSC can be attributed to the increase in sugar content during the ripening process (Ninama *et al.*, 2024) and sucrose hydrolysis to preserve the physiological activities of the fruit (Koehler *et al.*, 2012). Similar results have been reported for the packaging of guava with gum arabic-based film containing cinnamon essential oil (Cai *et al.*, 2020) and mango with biodegradable starch-based film containing thyme essential oil (Roopa *et al.*, 2015).

pH

Based on the results of the analysis of variance of the data shown in (Table 4), the main and interaction effects of all

the factors studied had a significant impact on the pH of the samples at the 5% probability level. Based on the results of the comparison across all treatments, the pH value increased over time, corresponding to the extended storage period. Additionally, in most treatments, the pH value decreased with the addition of essential oil to the packaging film and then remained constant at a concentration of 10%. However, with a concentration of 20%, the pH value decreased. These findings are attributed to the effects of respiration and consumption of organic acids caused by fruit aging during the storage period (Roopa *et al.*, 2015). As mentioned in the case of firmness, packaging with biopolymers that act as a selective barrier for CO₂ and O₂ and improve the atmosphere inside the package, reduce the respiration rate and consequently slow down the pH increase process in the product (Karnwal *et al.*, 2025). Similar results have been reported for guava packaging with gum Arabic-based film containing cinnamon essential oil (Etemadipoor *et al.*, 2019) and biodegradable PVA and chitosan film for Apple packaging (Ding *et al.*, 2019).

These acids in apples are expressed to a large extent by citric acid, which plays a role in regulating cell pH and may also affect the stability of anthocyanins and, consequently, fruit color (Ding *et al.*, 2019). It is thought that the consumption of organic acids and fruit aging are one of the factors affecting the reduction of acidity during storage (Khalifa *et al.*, 2016). According to research conducted by other researchers on the effect of packaging with biopolymer films (Rahman and Dutta, 2023; Shahbazi, 2018). Packaging materials can delay aging and, consequently, the number of organic acids used. On the other hand, the reduction in the amount of organic acids used with the presence and increase in the concentration of essential oils in the packaging film is attributed to the antimicrobial properties of essential oils and, consequently, the reduction

Table 3: Effect of different concentrations of Gelatin containing oregano (*Origanum vulgare* L.) essential oil on TSS in apples during storage.

Total soluble solids (Brix)	Storage period		
	5 th day	10 th day	15 th day
control	13.5±0.1c	15.2±0.4b	16.6±0.1a
Gelatin+5%	14.5±0.1b	15.3±0.2b	16.34±0.5a
Gelatin+10%	15.9±0.4b	15.1±0.8b	16.1±0.1a
Gelatin+20%	14.1±0.7b	15.3±0.8b	16.2±0.2a

Different litters mean significant differences at p<0.05.

Table 4: Effect of different concentrations of Gelatin containing oregano (*Origanum vulgare* L.) essential oil on the pH of apples.

pH	Storage period		
	5 th day	10 th day	15 th day
control	3.5±0.2a	4.9±0.4b	4.9±0.1b
Gelatin+5 %	3.9±0.3a	4.4±0.8b	4.7±0.7b
Gelatin+10%	3.8±0.4a	4.3±0.1b	4.5±0.7b
Gelatin+20%	3.7±0.6a	4.1±0.4b	4.5±0.1b

Different litters mean significant differences at p<0.05.

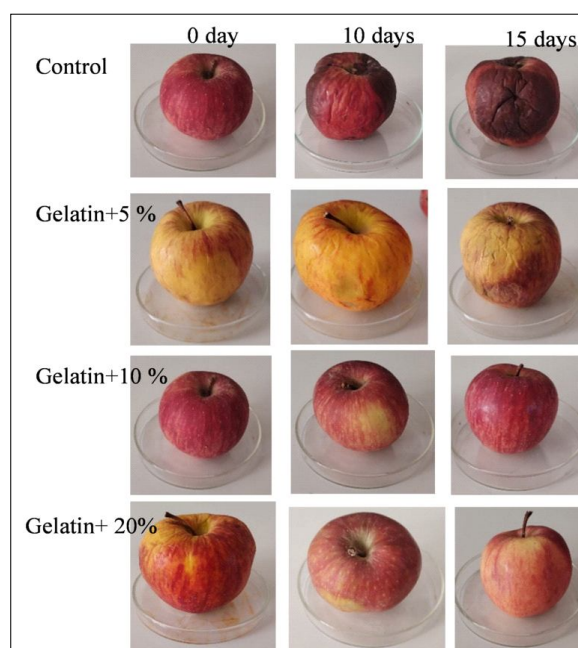


Fig 2: Effect of Gelatin containing oregano (*Origanum vulgare* L.) essential oil on the shelf-life of apples during storage.

in the rate of fruit deterioration due to the prevention of the spread of fungal contamination (Etemadipoor *et al.*, 2019). The results of the study by other researchers also indicate better pH maintenance with an increase in the concentration of oregano essential oil in the coating of apple with carboxymethylcellulose (Wang and Gao, 2013). Microbial spoilage based the effect of the type and concentration of essential oil and storage time on the microbial spoilage of the product was significant at the 1% probability level and their interaction at the 5% probability level. Based on the results of the comparison of the mean data shown in Fig 2, the number of contaminated samples increased with increasing storage time. However, the increased rate in the packaged samples containing essential oil was much lower than control treatments and packaged samples without essential oil. Also, the amount of microbial spoilage decreased with increasing concentration. So far, numerous studies have been conducted on the use of plant essential oils in the control of plant pathogenic fungi and the fungicidal properties of plant essential oils such as Shirazi thyme (Tahmasebi *et al.*, 2020; Tahmasebi *et al.*, 2020), cinnamon (Tahmasebi *et al.*, 2020; Tahmasebi *et al.*, 2020), Marza (Farzaneh *et al.*, 2015), mint (Liu *et al.*, 2016), ginger (Al-Shammari, 2024) and many others Plants and macroalgae (Ali *et al.*, 2024) have been proven to be effective in both *in vitro* and *in vivo*. Therefore, this reduction in fungal spoilage in the samples can be attributed to the presence of plant essential oils in the packaging film.

CONCLUSION

In this study, the storage time and the effect of different concentrations of oregano (*Origanum vulgare* L.) essential

oil in gelatin-based biodegradable active packaging on the post-harvest life of apples were investigated. The results of this study showed that during the treatment's storage period, the quality of the samples decreased; however, the decrease in the packaged samples was significantly less than in the unpackaged samples. Also, adding essential oil to the polymer film resulted in better preservation of the quality properties of apples and with increasing the concentration of essential oil, the decline in the quality of Apple samples was slower. Therefore, it seems that using biodegradable Gelatin film containing Shirazi thyme essential oil as an active packaging can greatly reduce post-harvest apple waste.

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Disclaimers

The views and conclusions expressed in this article are those of the authors alone and do not represent the opinions of their affiliated institutions. Although every effort has been made to ensure the information provided is accurate and complete, the authors cannot be held liable for any damages, direct or indirect, arising from the use of this content.

Conflict of interest

The authors affirm that there are no conflicts of interest in the publication of this article. Additionally, the design of the study, data collection, analysis, publication decisions and manuscript preparation were not influenced by any funding or sponsorship.

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