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Enhancing decay resistance and maintaining quality of stored apples (*Malus domestica* 'Golden Delicious') through essential oil-enriched edible coatings

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ABSTRACT

Purpose: Apples are susceptible to several diseases, which makes marketing and storage challenging. Therefore, it is critical to develop strategies that minimize weight loss while maintaining quality. **Research method:** Golden Delicious apples were coated with an edible mixture of *Aloe vera* gel (ALV) with or without *Zataria multiflora* essential oil (ZMO). Subsequently, the effects of these coatings on disease severity and incidence of *Botrytis cinerea* and *Penicillium expansum*, as well as storage quality features, were assessed. Inoculated apples with *B. cinerea* or *P. expansum*, the causative agents of apple postharvest gray and blue molds, were covered and stored at 25°C for 10 days and 2°C for 120 days. **Findings:** The antifungal ALV gel coatings significantly reduced the severity of gray and blue molds on inoculated apples, with the 150 $\mu L\ L^{-1}$ of ZMO-based coating showing the highest effectiveness. The ALV+ZMO coatings had the best results, exhibiting a lower decay index, and increased firmness, total phenol content, and antioxidant activity in the coated apples. The highest ripening index was observed in the control samples, which ranged from the initial value of 37.0 to 54.7 by the end of the storage period. Meanwhile, ALV alone was the most effective at decreasing weight loss. **Research limitations:** Thyme essential oil (EO) has limitations when used directly, inculding its strong odor and flavor, low stability, low water solubility, and high volatility**. Originality/Value:** Overall, ALV and ZMO edible coatings appear to be a viable solution for suppressing fungal infections while maintaining apple quality under both situations.

INTRODUCTION

The apple fruit plays a beneficial role in providing antioxidant protection to the human body due to its rich source of phytochemicals such as flavonoids and phenolic acids (Mannucci et al., 2017). Global apple production in 2023-2024 exceeded 83 M tons (FAS, 2024). There is a growing market demand for fresh fruit available year-around. However, despite the market demands for fresh apples throughout the year, their shelf-life diminishes rapidly due to physiological changes and fungal decay (Mostafidi et al., 2020). Postharvest apple losses are primarily caused by postharvest fungal pathogens such as *Botrytis cinerea* and *Penicillium expansum*, the agents responsible for gray and blue mold, which adversely affect fruit safety and quality, resulting in significant economic losses (Glos et al., 2022).

Developing eco-friendly alternative methods, including bio-control agents containing bioactive and chemical compounds (Li et al., 2017), sodium de-hydro acetate (Duan et al., 2016), and natural antimicrobial substances (Esmaeili et al., 2021; Rahimi Kakolaki et al., 2024) to inhibit postharvest fungal decay is becoming increasingly important (Moradinezhad & Ranjbar, 2023). In recent decades, edible films and coatings have been recognized as cost-effective and environmentally friendly techniques that can extend the shelf life of products, both during storage and when being sold in shops and marketplaces (Panchal et al., 2022).

Aloe vera (ALV) gel edible coating is a natural polysaccharide that contains a variety of biological components (Supa et al., 2024). It serves as a rich source of antimicrobial and antioxidant agents, such as phenolic compounds which include anthraquinones, emodin, and aloin (Habibi et al., 2022). Additionally, *Aloe vera* can trigger defense responses in plant tissues (Hassan et al., 2022). These properties of *Aloe vera* are attributed to its high polysaccharides content along with vitamins, soluble sugars, minerals (such as calcium, chromium, copper, selenium, magnesium, manganese, potassium, sodium and zinc), proteins, and a relatively low fat content (Pandey & Singh, 2016). To increase the lipid content, essential oils rich in fatty acids like *Zataria multiflora* essential oil (ZMO) can be incorporated into the treatment, which has been shown to effectively manage deterioration and prolong the overall quality and shelf life of fresh produce (Hashemi et al., 2021; Jahanshahi et al., 2023).

A combination of polysaccharides and lipids has been suggested to enhance the efficacy of the coating treatment. This study aimed to investigate the protective effect of ALV alone or in combination with ZMO in managing gray and blue mold caused by *B. cinerea* and *P. Expansum*. The influence of these treatments and fungal inoculation on fruit quality and physiological characteristics was also evaluated. Additionally, the effectiveness of ALV and ZMO as a novel coating was investigated concerning the physicochemical and sensory properties of the fruit during cold storage.

MATERIALS AND METHODS

'Golden Delicious' apple fruits (*Malus domestica* Brokh) were manually harvested at commercial maturity (140 days after full bloom) from an orchard in Chenaran, located in North-East Iran's Khorasan region. The collection of plant material adhered to applicable institutional, national, and international guidelines and legislation, with permission obtained for the plant material collection. The fruits were sterilized with 1% sodium hypochlorite for 2 min, followed by washing with tap water, disinfection with 70% ethanol, and air-drying at room temperature.

Inoculum preparation

The fungi used in this study were *Botrytis cinerea* ATCC (12481) and *Penicillium expansum*, obtained from the Iranian Research Organization for Science and Technology and the Agriculture Biotechnology Research Institute of Iran, respectively. The fungal strains were cultured on Potato Dextrose Agar (PDA) at 28±2°C for 5-10 days. Suspensions were prepared by immersing the culture in distilled water and filtered through two layers of cheesecloth. The inoculum size was assessed using a hemocytometer and adjusted to a concentration of 5×10 conidia ml^{-1} for each strain (Oliveira et al., 2015).

Preparation of *Aloe vera* gel (ALV) and *Zataria multiflora* essential oil (ZMO)

Mature and fresh leaves of the *Aloe vera* plant were harvested from a greenhouse located on Ferdowsi university of Mashhad's campus. The mucilaginous gel was extracted from the outer portion and blended using a blender. The gel's properties were determined as pH 4.63±0.02, total soluble solids=1.5±0.05%, and acidity=0.043±0.003% citric acid. The gel was stabilized by adjusting the pH to 3.75 with phosphoric acid (Navarro et al., 2011), then pasteurized by heating at 80°C for 10s, and cooled down to 5°C for further use (Jiwanit et al., 2018). The gel was diluted with deionized water to achieve a 60% (v/v) concentration. The Persian thyme plants, at a full bloom, were harvested from the major growing area of Khorasan in Mid-June of 2022. The essential oil was extracted through hydro-distillation utilizing a Clevenger apparatus for 3h. The obtained oil was then dried with anhydrous sodium sulfate and stored in sealed vials at 4°C for further use.

Treatment application of antifungal coating

The main experiment was divided into two parts; in the first part, the fruits were kept at 25°C for 10 days, and in the second part, the fruits were stored at 2°C for 120 days' post-treatment. Apple fruits were selected and randomly divided into 13 groups, each consisting of 12 samples. There were 12 replications per treatment (n=12). One group was used for analyzing the fruit characteristics at harvest. while the remaining samples were used for the following treatments: control (untreated), 60% ALV gel, 150 µL L^{-1} of ZMO, and 60%ALV+150 µL L^{-1} of ZMO (ALV+ZMO). Before the treatments, the fruits were artificially wounded (approximately 5 mm in depth) near the equatorial region of the fruit using a sterile cork borer. Three groups of 12 fruits each were treated for 10 min by immersing them in the respective treatment (distilled water, 60%ALV, 150 µL L^{-1} of ZMO, and 60%ALV+150 µL L^{-1} of ZMO) and then allowed to dry at room temperature. Twenty-four hours after the treatments, two groups of each treatment were inoculated with *B. cinerea* (gray mold) and *P. Expansum* (blue mold) by depositing 20 µl of the pathogen suspensions (5×10 conidia ml^{-1}) into the previously created wounds. One group from each treatment served as a control without fungus inoculation. All fruits were stored at 25°C and 90-95% relative humidity for 10 days. The experiment was replicated, and lesion diameter and disease severity were measured 10 days after treatment and storage at 25°C. The primarly factor considered was the types of essential oils (ALV and ZMO), while the secondary factor was the presence of two types of fungi (*Botrytis cinerea* and *Penicillium expansum*). Following the 10 days treatment and storage at 25°C, measurements were taken for antioxidant activities, firmness, and total phenol content. The primary factor considered here was the different types of essential oils (ALV and ZMO), and the secondary factor was present and absent of the two fungi strains (*Botrytis cinerea* and *Penicillium expansum*). Decay index, weight loss, antioxidant activities, firmness, and total phenol content were measured at a temperature of 2°C. The primary factor considered here was the different concentrations of essential oils, while the secondary factor was the timing of measurement.

Microbiological analysis infection

After 10 days, the disease incidence of gray and blue mold was calculated by measuring the average diameter of the damaged area (lesion diameter). Disease severity was assessed using a five-point scale based on the extent of damage, with the following categories: 1=0% of surface rotten per fruit, 2= 10-25%, 3= 26-50%, 4=51-75% and 5= 76-100% rotten (Maqbool et al., 2011).

Fruit quality

In the second part of the experiment, the effect of the edible ALV coatings enriched with ZMO on the decay index and quality of apple fruit during 120 days of storage at 2±1°C was investigated. The treatments included: control group (without coating), 60%ALV, 150 μL L^{-1} of ZMO, and 60%ALV+150 μL L^{-1} of ZMO. The fruits were divided into 64 groups with ten apple fruits per group, and there were four replications of each treatment. Each fruit was cut in half along the equator to assess internal symptoms of physiological disorders and decay, using the following scale: 0= no decayed fruit; 1= slight (<25% decay); 2= moderate symptoms (25%-50% decay); and 3= sever (>50% decay) (Laribi et al., 2013).

12 fruits per treatment were used to measure weight loss (WL), which was expressed as the percentage loss of initial weight. Firmness was assessed using a penetrometer model (Effegi-mod FT327). The ripening index was considered as TSS/TA ratio. Total soluble solid (TSS) was determined at 2 °C using a portable refractometer (Atago; Japan). Titratable acidity (TA) was measured through titrating 15 ml of diluted juice in 60 ml of distilled water with 0.1N sodium hydroxide until reaching the endpoint of 8.2, and expressed as malic acid percentage. The total phenol content was analyzed using the Follin-ciocalteu reagent (Singleton & Rossi, 1965). The antioxidant activity of apple juice was measured based on free radical scavenging capacity using the DPPH method (Gil et al., 2000).

Statistical analysis

Statistical analysis was performed using JMP 9 statistical software (SAS, Institute, and Cary, NC). The results were statically assessed via multi-factorial analysis of variance (ANOVA) with a 95% confidence level using Fisher's LSD procedure, where $P < 0.05$.

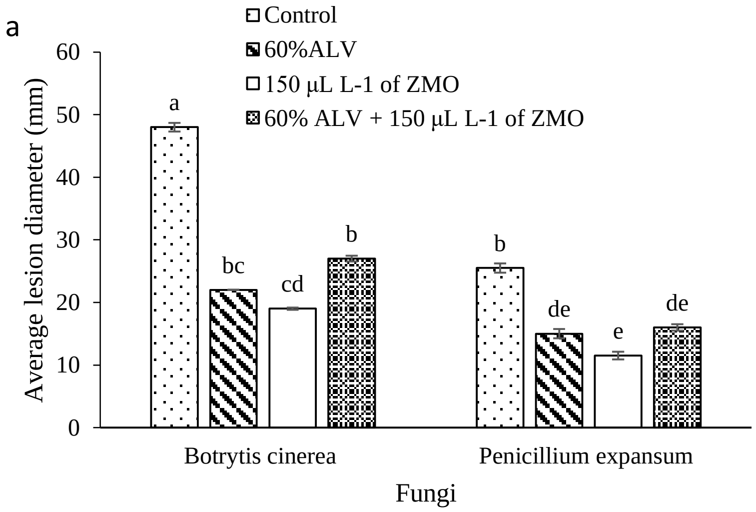
RESULTS AND DISCUSSION

The *Aloe* gel and ZMO treatments used in the current study showed a significant effect ($P<0.01$) on inhibiting the development of gray and blue mold decay (Table 1, Fig. 1A and B). However, the application of treatments (ALV alone, ALV combination with ZMO) resulted in greater reduction in lesion diameter and disease severity compared to untreated apples. Higher lesion diameters of *Botrytis cinerea* (48.5mm) and *Penicillium expansum* (24.5mm) were observed in the control group, whereas the lowest values were observed with 60%ALV+ZMO 150 μL L^{-1}. The treatments using ALV coating alone or in combination ZMO significantly reduced the lesion diameter caused by gray mold (54.2% and 61.03%, respectively) and blue mold (37.3% and 48.08%, respectively) compared to the control (Fig. 1A). When considering the interaction between treatments and fungi, the highest disease severity (5 scores) was observed in the control group, while the lowest disease severity (1.3 scores) was seen in fruit treated with coating (60%ALV+ZMO150 μL L^{-1}) and infected with *Penicillium expansum*. Additionally, there were no notable variations in disease severity between fruit infected with *Botrytis cinerea* and treated with 60% ALV alone and those treated with 60% ALV and 60%ALV+ZMO150 μL L^{-1} (Fig. 1B).

Table 1. ANOVA analysis of the impact of essential oil (ALV and ZMO) and fungal species (*Botrytis cinerea* and *Penicillium expansum)* on the avarage lesion diameter and disease severity of apple after 10 days at 25 °C.

Sources of variations	df	Mean Square Avarage lesion diameter	 Disease severity
Fungus	1	852^{**}	0.24^{ns}
Treatments	3	534^{**}	1.72^{ns}
Fungus×Treatments	3	74.8^{**}	5.32^{**}
Error	3	2.17	0.974

** Significance at the level of <0.01 probability, ^{ns} non significant.



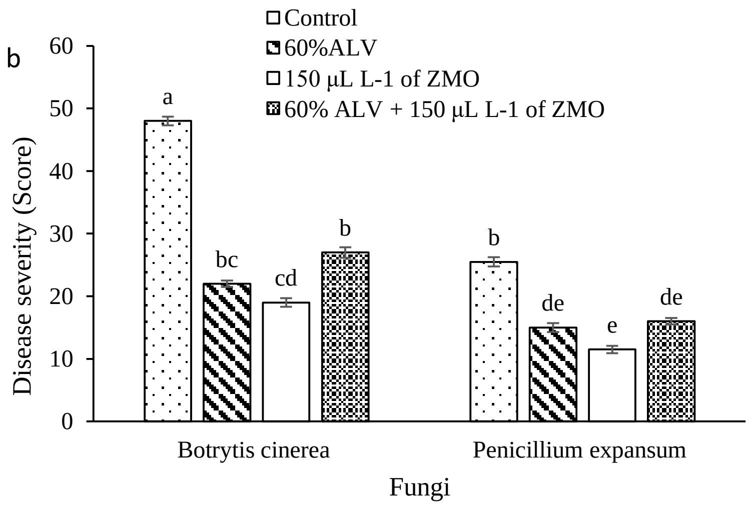


Fig. 1. Effect of 60% ALV alone or combination with ZMO on the lesion diameter (a) and disease severity of apple fruit caused *Botrytis cinerea* and *Penicillium expansum* (b), at 25 °C for 10 days. Error bars represent the mean ± SE.

The experiment was conducted under ideal conditions, as mature fruits were artificially inoculated with a high level of inoculum pressure to induce disease development, specifically without applying low temperatures. Previous studies have also shown that the use of ALV significantly reduced the lesion size (Navarro et al., 2011; Jiwanit et al., 2018). Al-Hassanavi et al. (2023) showed that basil and permint essential oils reduced the lesion diameter in apple fruits infected with *Penicillium expansum*. The main compounds of this ZMO are thymol and carvacrol, constituting 42.46% and 16.85%, respectively (Lahooji et al., 2010). The antifungal effects of ZMO are primarily atributable to its phenolic monoterpene constituents (Avaei et al., 2015). The ZMO is a rich source of oxygenated monoterpenes that cause destabilization and morphological damage to fungal cell membranes (Mohammadi et al., 2016), as well as disrupt various metabolic activities (Ramezanian et al., 2016). The ALV-based edible coating is a combination of hydrocolloids which provides excellent gas barrier properties (Luciano-Rosario et al., 2020). It also helps reduce oil-vapor diffusion and maintain essential oil on the fruit surface (Ali et al., 2015). Meanwhile, the antifungal properties of ALV are related to certain predominant anthraquinone such as aloin and barbaloin, which may effectively affect phospholipid membranes, leading to significant changes in the physical properties of the membrane. These alternations could include disruption of bilayer phospholipid membranes (Zapata et al., 2013).

The decay index, firmness, ripening index, total phenol content, and antioxidant activity of apples were significantly affected by the interaction of essential oil (ALV and ZMO) and the storage period at 2 °C (0, 30, 60, 90 and 120 days) (Fig. 2). The ALV and ZMO treatments during storage period had a significant ($P<0.01$) effect on the decay index. Uncoated apples showed the first signs of decay after 60 days of storage at low-temperature. By 120 days of storage, the control fruits exhibited decay indices at moderate and severe levels, while coated fruits showed either no decay or only slight signs (Fig. 2).

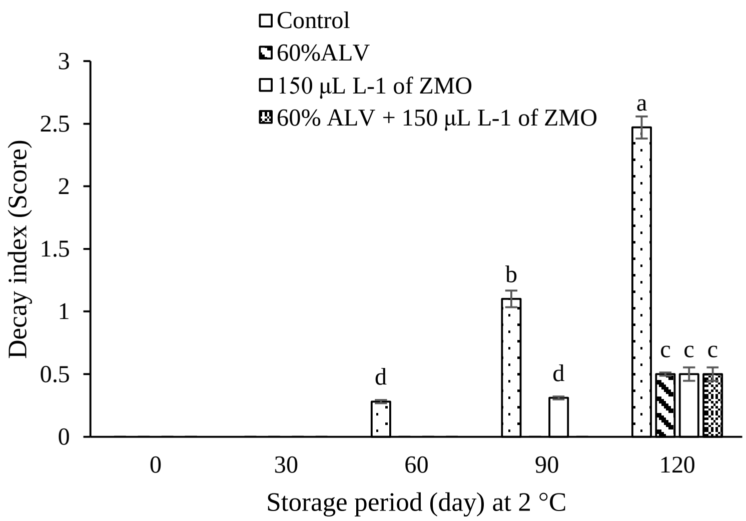


Fig. 2. Effect of 60% ALV alone or combination with ZMO on Decay index of apple fruit, followed by storage at low temperature (2 ℃, 120 days). Error bars represent the mean ± SE.

Table 2. ANOVA analysis of the impact of essential oil (ALV and ZMO) and storage period at 2 °C (0, 30, 60, 90 and 120th*)* on the decay index, firmness, ripening index, total phenol content, and antioxidant activity of apple.

Sources of variations	df	Mean Square				
		Decay index	Firmness	Ripening index	Total phenol content	Antioxidant activity
Treatments	3	1.59**	11.6**	79.2**	5.41**	1962**
Time	4	2.14**	32.1**	297**	13.2**	4248**
Treatments×Time	12	0.546**	5.03**	15.9**	2.91**	884**
Error	40	0.03	0.019	0.925	0.007	0.62

** Significance at the level of <0.01 probability

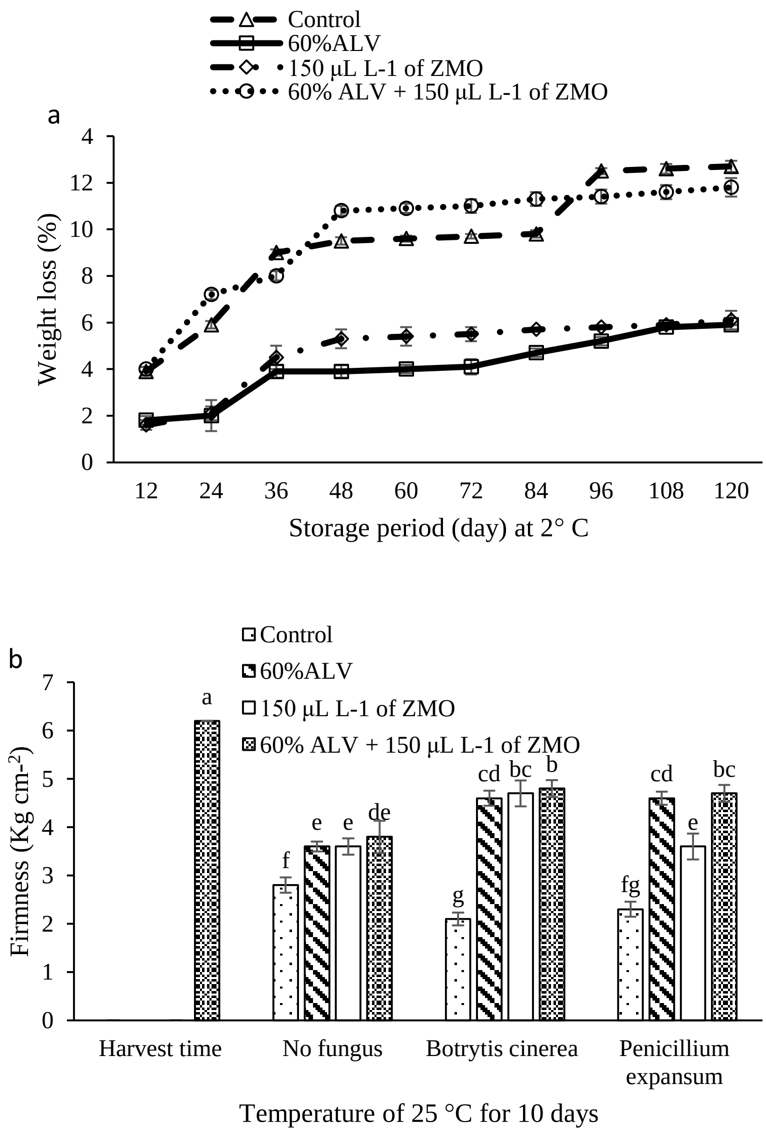
The ALV, ZMO, and ALV combined with ZMO coatings were effective in preserving the quality of apples during cold storage, probably due to their ability to reduce dehydration and shriveling of the coated apples. Previous studies have shown that ZMO has antifungal against postharvest fruit pathogens, such as *Phytophthora drechsleri* in cucumber (Ramezanian et al., 2016), and *Alternaria citri* in oranges (Mohammadi et al., 2016). ALV coatings have also been reported to enhance resistance against decay agents in raspberry (Hassanpour, 2015), and papayas (Mendy et al., 2019). ALV and ZMO can also increase tissue resistance to decay by increasing the ability to scavenge free radicals and improving the antioxidant system. The presence of phenolic compounds can influence antioxidant activity (Hidayati et al., 2020). Phenolic compounds and flavonoids, acting as key antioxidants, may have a significant play in absorbing and neutralizing free radicals, thereby preventing decay progression in fruit (Hassan et al., 2021). In apples coated with ALV and ZMO, the storage time was extended, as this treatment reduced the decay rate. Therefore, ALV with ZMO helps to maintain the quality of apples during storage.

The weight of apples inoculated with fungus did not show any statisticat differences (P≤0.05) after 10 days at room temperatures (data not shown). Figure 3 displays the changes in weight of coated and uncoated samples stored at 2°C for 120 days. There was an increase in weight loss across all treatments during storage. By day 120, apples treated with ALV, ALV+ZMO, and ZMO had weight losses of 5.9%, 11.6%, and 6.6%, respectively, which were lower than in the control group at 16.5%. Contrary to expectations, the weight loss of the ALV+ZMO treated fruits was higher than that of just ALV treated fruits (Figure 3A). The ALV and ZMO treatments during storage at 2 °C had a significant (P<0.01) effect on the firmness, total phenol content, ripening index and antioxidant activity of the apples (Table 1). Fruits treated with ALV (alone or with ZMO) and ZMO were significantly firmer than untreated fruits in both experimental conditions. The firmness of untreated fruits after 120 days of storage at 2°C and after 10 days at 25°C was 37.9%, and 58.3%, respectively, and 67.8%, 65.2% for fruit inoculation with *B. cinerea* and *P. expancum*, respectively with respect to the initial force value of fruit before treatment (6.1 kg cm^2). Meanwhile, firmness loss for all treated fruits was less than 38% under the same conditions. On the other hand, the fruit firmness of ALV alone, ALV+ZMO, and ZMO treatments decreased by 28.9%, 21.2%, 26.5%, and 29.7%, 25.7%, 41.2% when they were inoculated with *B. cinerea* and *P. expancum,* respectively. The application of ALV alone or combined with ZMO was most effective in reducing the softening process. Nevertheless, the type of fungal inoculation did not significantly affect the firmness retention (Fig. 3B and C).

Table 3. ANOVA analysis of the impact of essential oil (ALV and ZMO) and fungal species (*Botrytis cinerea* and *Penicillium expansum)* on the firmness, ripening index, and antioxidant activity of apple after 10 days at 25°C.

Sources of variations	df	Mean Square			
		Firmness	Total phenol content	Ripening index	Antioxidant activity
Treatments	3	18.6**	5.87**	79.2**	2690**
Fungus	3	5.2**	6.08**	297**	5673**
Treatments× Fungus	9	6.4**	4.04**	15.9**	1077**
Error	32	0.012	0.021	0.925	0.77

** Significance at the level of <0.01 probability.



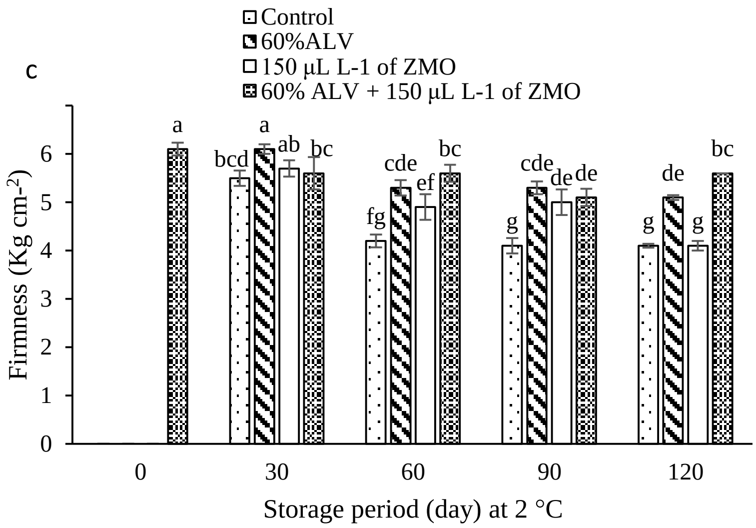


Fig. 3. Effect of 60% ALV alone or combination with ZMO on weight loss (%) of apple fruit, followed by storage at low temperature (2°C, 120 days) (a), firmness in artificially inoculated and non-inoculated apple fruit, followed by storage at room temperature (25°C, 10 days) (b) and low temperature (2°C, 120 days) (c). Error bars represent the mean ± SE.

The highest WL was observed for pears covered with a containing coating potassium sorbate on the 9th day, with the WL of fruits nearly double that of the control (Kowalczyk et al., 2017). Although polysaccharide coatings may not provide the best moisture barrier (Synowiec et al., 2014), ALV plays an important role in the reducing CO_2 production and preventing moisture loss in sweet cherry fruit during storage. The reduction of weight loss has also been observed in papaya coated with ALV gel (Mendy et al., 2019). On the other hand, Dashipour et al. (2015) demonstrated that adding ZMO to carboxymethylcellulose film actually enhanced its water vapor permeability. They provided reasons for this, pointing out that while the presence of ZMO increased the hydrophobicity ratio of films, it also decreased the cohesion of the film due to the microdroplets of ZMO. This can be attributed to the increased tortuosity and hydrophobicity caused by the essential oils. Changes in cell wall components and middle lamella were associated with the degradation of cellulose and hemicellulose as well as the depolymerization of pectin (Thakur et al., 2018), due to the activity of degrading enzymes such as polygalacturonase, pectin methylesterase, and β-galactosidase, which are main key factors in ethylene production and softening climacteric fruit postharvest (Valero et al., 2013). ZMO was found to help maintain the fruit firmness by reducing the activity of the endo polygalacturonase enzyme (Nasiri et al., 2017). ALV treatments have been shown to be an effective method for reducing the loss of firmness in various fruit and vegetables during storage (Khatri et al., 2020). The reduced water vapor in fruits coated with ALV gel results in maintaining turgor pressure in the cell walls. The *Aloe vera*-treated fruits with ZMO showed slightly higher strength, possibly due to the increased hydrophobic properties in this treatment (Hasan, et al., 2021).

The ripening index (TSS/TA) increased in all treatments over the storage period at 2°C (Fig. 4). The highest ripening index was observed in the control samples, which ranged from the initial value of 37.0 to 54.7 by the end of the storage period. The increase was lower with the ALV alone (43) and ALV+ZMO (46.9) treatments, on the 120th day of storage. However, there was no significant difference between ALV and ALV+ZMO treatments.

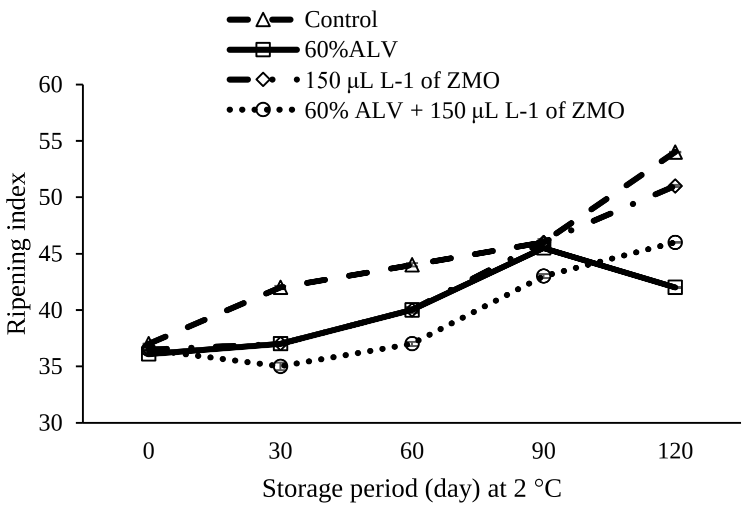
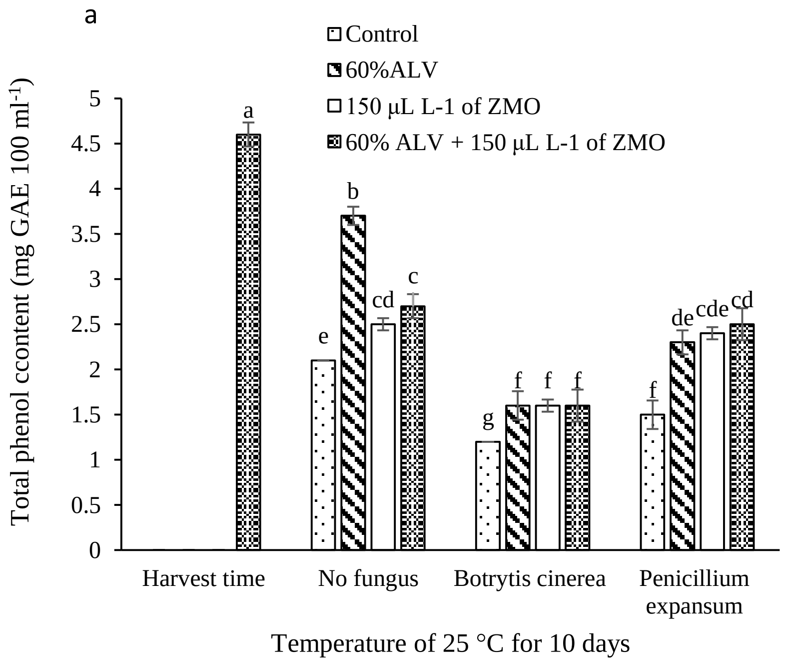


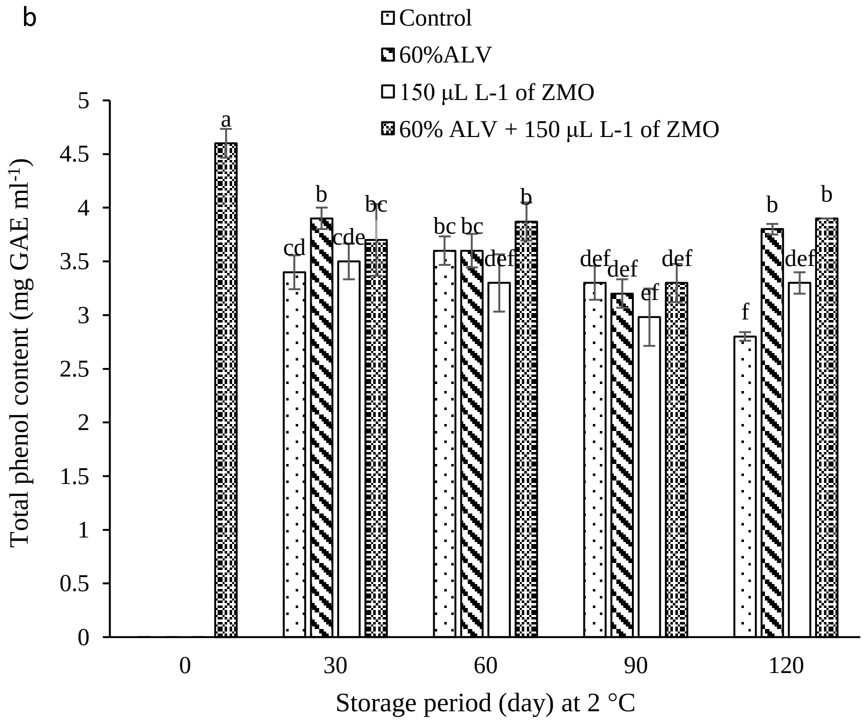
Fig. 4. Effect of 60% ALV alone or combination with ZMO on ripening index of apple fruit, followed by storage at low temperature (2°C, 120 days). Error bars represent the mean ± SE.

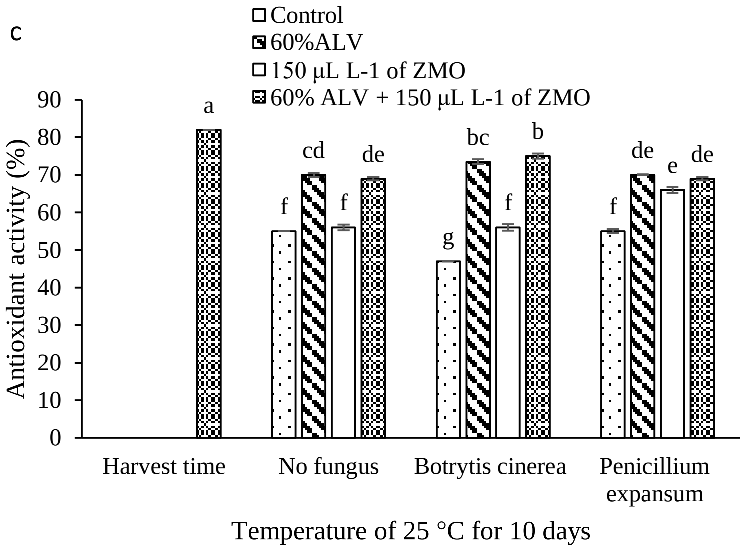
The most significant reduction in the ripening index was observed in the coating treatment ALV incorporation with ZMO throughout the storage period. The initial increase in TSS could be attributed to the hydrolysis of starch to sugars, while the subsequent decrease in TSS may be a result of the reduced respiration rate and metabolism of sugars to organic acids (Shehata et al., 2020). Lower TSS levels could be related to the hydrolysis of carbohydrates to sugars (Rehman et al., 2020). The amount of TA in fruit is directly related to the organic acid content (Shehata et al., 2020). The fruit acidity tends to decrease over time, possibly due to the oxidation of organic acids during fruit ripening. The edible fruit layers reduce the respiration rate, leading to a decrease in the consumption of organic acids in the respiration metabolism of the fruit (Dhital et al., 2018). The ALV coating could modify the internal atmosphere of coated fruits (Mendy et al., 2019); consequently, leading to a decline in ethylene biosynthesis, and acid and sugar metabolism in the fruit (Martínez-Romero et al., 2017). Overall, the ripening process was delayed using ALV coating alone or in combination with ZMO. Similar results have been reported in the case of apples coated with carnauba-shellac wax enriched with lemongrass oil (Jo et al., 2014), and guavas coated with both chitosan, and alginate enriched with pomegranate peel extract (Nair et al., 2018).

There were significant differences ($P \leq 0.05$) in the total phenol content between the control apples and those coated with ALV, ALV+ZMO, and ZMO throughout the storage period at both room and low temperatures. However, there were some fluctuations in the total phenol content observed during the storage of coated apples at 2°C. The total phenolic content was (4.7mg GAE 100 ml^{-1}) at harvest time and it decreased in all treatments after storage at 2°C and 25°C (Figures 5A and B). The inoculation of fruits with the two fungi exhibited a sharp decline in the total phenolic content compared with non-inoculated fruits (Fig. 5A). Coated apples generally had a higher total phenolic content than uncoated apples (Fig. 5A and B). In the most of samples, there is no significant difference between antioxidant activity of infected apples with *Penicillium expansum* compared to non-infected apple treated with essential oil. Although, after 10 days at 25 C, the antioxidant activity of ALV+ZMO apples infected by *Botrytis cinerea* increased significantly compared to non-infected apples (Fig. 5C). The antioxidant activity of all samples on 90th day significantly decreased compared to

30th day, although no significant difference was observed between treatments on 30th days and 120th days (Fig. 5D).







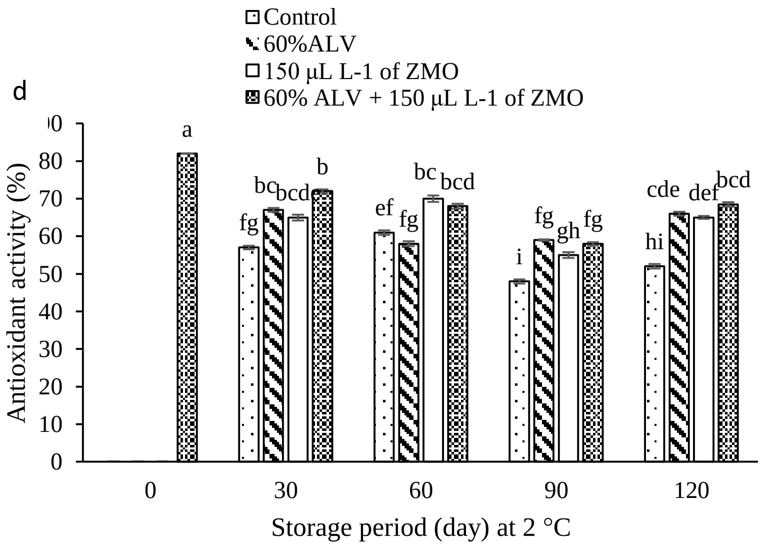


Fig. 5. Effect of 60% ALV alone or combination with ZMO on total phenolic content in artificially inoculated and non-inoculated apple fruit, followed by storage at room temperature (25°C, 10 days) (a) and low temperature (2°C, 120 days) (b), and antioxidant activity, followed by storage at room temperature (25°C, 10 days) (c) and low temperature (2°C, 120 days) (d). Error bars represent the mean ± SE

The ALV coating treatment effectively declined the loss of total phenol content, possibly by increasing phenylalanine ammonia-lyase enzyme (PAL) activity. Hassanpour (2015) observed that ALV coating can stimulate PAL enzyme activity. Jiwanit et al. (2018) reported that ALV coating enriched with *Pichia guilliermondii* efficiently increased total phenol content and reduced pathogen growth. In ZMO treatment, phenolic compounds such as thymol and carvacrol have been shown to be effective against pathogenic fungi (Nasiri et al., 2017). Total phenol content has been reported to be inducers of plant defense response (Kharchoufi et al., 2018). The postharvest application of ALV and ZMO increased resistance against fungal pathogens since they may act as an exogenous elicitor of host-defense response (Jiwanit et al., 2018). The reduction of total phenol content and antioxidant activity during storage could be related to fruit senescence and the breakdown of cell structures (Ghasemnezhad et al., 2013). Edible coatings play an inhibitory role in controlling the gas exchange between the fruit and its surrounding areas, reducing oxygen intake and thus retarding oxidative processes (Motamedi et al., 2016). ALV show greater antioxidant capacity than synthetic BHT or α-tocopherol, where ALV could enhance the resistance of the tissue to decay by increasing its antioxidant system and its free radical scavenging capability (Hassanpour, 2015).

CONCLUSION

In this research, we examined the impact of using ALV gel with and without ZMO as a new type of edible coating on the quality of apple fruit postharvest. The application of the coating on the fruit surface resulted in a delay in the severity and occurrence of diseases caused by *Botrytis cinerea* and *Penicillium expansum* , with the most effective treatments found to be at 150 µL L-1 of ZMO. Additionally, the addition of ZMO essential oil to the *Aloe vera* gel showed positive effects on preserving the firmness, total phenol content, and antioxidant activity of the apples.

Conflict of interest

The authors at this moment hereby declare that there is no conflict of interest.

REFERENCES

Avaei, A., Mohamadi Sani, A., & Mahmoodzadeh Vaziri, B. (2015). Chemical composition and antimicrobial effect of the essential oil of Zataria multiflora Boiss endemic in Khorasan-Iran. *Asian Pacific Journal of Tropical Disease*, *5*(3), 181-185. https://doi.org/10.1016/S2222-1808(14)60649-6

Al-Hassanavi, H., Rostami Tobnag, G., & Shokri, R. (2023). Application of essential oils and optimizing storage conditions for control of postharvest diseases in apple. *Advances in Horticultural Science*, *37*(2). https://doi.org/10.36253/ahsc-13919

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. https://doi.org/10.1016/j.fpsl.2014.10.003

Dashipour, A., Razavilar, V., Hosseini, H., Shojaee-Aliabadi, S., German, J. B., Ghanati, K., Khakpour, M., & Khaksar, R. (2015). Antioxidant and antimicrobial carboxymethyl cellulose films containing Zataria multiflora essential oil. *International journal of biological macromolecules*, *72*, 606-613. https://doi.org/10.1016/j.ijbiomac.2014.09.006

Dhital, R., Mora, N. B., Watson, D. G., Kohli, P., & Choudhary, R. (2018). Efficacy of limonene nano coatings on post-harvest shelf life of strawberries. *Lwt*, *97*, 124-134. https://doi.org/10.1016/j.lwt.2018.06.038

Duan, X., Jing, G., Fan, F., & Tao, N. (2016). Control of postharvest green and blue molds of citrus fruit by application of sodium dehydroacetate. *Postharvest Biology and Technology*, *113*, 17-19. https://doi.org/10.1016/j.postharvbio.2015.10.015

Esmaeili, Y., Paidari, S., Baghbaderani, S. A., Nateghi, L., Al-Hassan, A. A., & Ariffin, F. (2022). Essential oils as natural antimicrobial agents in postharvest treatments of fruits and vegetables: A review. *Journal of Food Measurement and Characterization*, 16, *507–522*. https://doi.org/10.1007/s11694-021-01178-0

FAS, United States Department of Agriculture Foreign Agricultural Service https://fas.usda.gov/data/production/commodity/0574000 (accessed 2024).

Ghasemnezhad, M., Zareh, S., Rassa, M., & Sajedi, R. H. (2013). Effect of chitosan coating on maintenance of aril quality, microbial population and PPO activity of pomegranate (*Punica granatum* L. cv. Tarom) at cold storage temperature. *Journal of the Science of Food and Agriculture*, *93*(2), 368-374. https://doi.org/10.1002/jsfa.5770

Gil, M. I., Tomás-Barberán, F. A., Hess-Pierce, B., Holcroft, D. M., & Kader, A. A. (2000). Antioxidant activity of pomegranate juice and its relationship with phenolic composition and processing. *Journal of Agricultural and Food chemistry*, *48*(10), 4581-4589. https://doi.org/10.1021/jf000404a

Glos, H., Bryk, H., Michalecka, M., & Puławska, J. (2022). The recent occurrence of biotic postharvest diseases of apples in Poland. *Agronomy*, *12*(2), 399. https://doi.org/10.3390/agronomy12020399

Habibi, A., Yazdani, N., Chatrabnous, N., Koushesh Saba, M., & Vahdati, K. (2022). Inhibition of browning via aqueous gel solution of Aloe vera: a new method for preserving fresh fruits as a case study on fresh kernels of Persian walnut. *Journal of Food Science and Technology*, 59, 2784–2793 https://doi.org/10.1007/s13197-021-05301-3

Hasan, M. U., Riaz, R., Malik, A. U., Khan, A. S., Anwar, R., Rehman, R. N. U., & Ali, S. (2021). Potential of Aloe vera gel coating for storage life extension and quality conservation of fruits and vegetables: An overview. *Journal of Food Biochemistry*, *45*(4), e13640. https://doi.org/10.1111/jfbc.13640

Hashemi, M., Dastjerdi, A. M., Mirdehghan, S. H., Shakerardekani, A., & 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

Hassan, H. S., EL-Hefny, M., Ghoneim, I. M., El-Lahot, M. S. A., Akrami, M., Al-Huqail, A. A., ALI H.M., & Abd-Elkader, D. Y. (2022). Assessing the use of aloe vera gel alone and in combination with lemongrass essential oil as a coating material for strawberry fruits: HPLC and EDX analyses. *Coatings*, *12*(4), 489. https://doi.org/10.3390/coatings12040489

Hassanpour, H. (2015). Effect of Aloe vera gel coating on antioxidant capacity, antioxidant enzyme activities and decay in raspberry fruit. *LWT-Food Science and Technology*, *60*(1), 495-501. https://doi.org/10.1016/j.lwt.2014.07.049

Hidayati, J. R., Yudiati, E., Pringgenies, D., Oktaviyanti, D. T., & Kusuma, A. P. (2020). Comparative study on antioxidant activities, total phenolic compound and pigment contents of tropical *Spirulina platensis*, *Gracilaria arcuata* and *Ulva lactuca* extracted in different solvents polarity. In *E3S Web of Conferences* (Vol. 147, p. 03012). EDP Sciences.

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

Jiwanit, P., Pitakpornpreecha, T., Pisuchpen, S., & Leelasuphakul, W. (2018). The use of Aloe vera gel coating supplemented with Pichia guilliermondii BCC5389 for enhancement of defense-related gene expression and secondary metabolism in mandarins to prevent postharvest losses from green mold rot. *Biological control*, *117*, 43-51. https://doi.org/10.1016/j.biocontrol.2017.08.023

Jo, W. S., Song, H. Y., Song, N. B., Lee, J. H., Min, S. C., & Song, K. B. (2014). Quality and microbial safety of 'Fuji'apples coated with carnauba-shellac wax containing lemongrass oil. *LWT-Food Science and Technology*, *55*(2), 490-497. https://doi.org/10.1016/j.lwt.2013.10.034

Kharchoufi, S., Parafati, L., Licciardello, F., Muratore, G., Hamdi, M., Cirvilleri, G., & Restuccia, C. (2018). Edible coatings incorporating pomegranate peel extract and biocontrol yeast to reduce *Penicillium digitatum* postharvest decay of oranges. *Food Microbiology*, *74*, 107-112. https://doi.org/10.1016/j.fm.2018.03.011

Khatri, D., Panigrahi, J., Prajapati, A., & Bariya, H. (2020). Attributes of Aloe vera gel and chitosan treatments on the quality and biochemical traits of post-harvest tomatoes. *Scientia Horticulturae*, *259*, 108837. https://doi.org/10.1016/j.scienta.2019.108837

Kowalczyk, D., Kordowska-Wiater, M., Zięba, E., & Baraniak, B. (2017). Effect of carboxymethylcellulose/candelilla wax coating containing potassium sorbate on microbiological and physicochemical attributes of pears. *Scientia Horticulturae, 218*, 326-333. https://doi.org/10.1016/j.scienta.2017.02.040

Lahooji, A., Mirabolfathy, M., & Karami-Osboo, R. (2010). Effect of *Zataria multiflora* and *Satureja hortensis* essential oils, thymol and carvacrol on growth of *Fusarium gramineum* isolates and deoxynivalenol production. *Iranian Journal of Plant Pathology, 46, 37-50.*

Laribi, A. I., Palou, L., Taberner, V., & Pérez-Gago, M. B. (2012). Modified atmosphere packaging to extend cold storage of pomegranate cv.'Mollar de Elche'. In Proceedings of the International Conference of Agricultural Engineering—CIGR-AgEng.

Li, J., Lei, H., Song, H., Lai, T., Xu, X., & Shi, X. (2017). 1-methylcyclopropene (1-MCP) suppressed postharvest blue mold of apple fruit by inhibiting the growth of *Penicillium expansum*. *Postharvest Biology and Technology*, *125*, 59-64. https://doi.org/10.1016/j.postharvbio.2016.11.005

Luciano-Rosario, D., Keller, N. P., & Jurick, W. M. (2020). *Penicillium expansum*: Biology, omics, and management tools for a global postharvest pathogen causing blue mould of pome fruit. *Molecular Plant Pathology*, *21*(11), 1391-1404. https://doi.org/10.1111/mpp.12990

Mannucci, A., Serra, A., Remorini, D., Castagna, A., Mele, M., Scartazza, A., & Ranieri, A. (2017). Aroma profile of Fuji apples treated with gelatin edible coating during their storage. *LWT-Food Science and Technology*, *85*, 28-36. https://doi.org/10.1016/j.lwt.2017.06.061

Maqbool, M., Ali, A., Alderson, P. G., Mohamed, M. T. M., Siddiqui, Y., & Zahid, N. (2011). Postharvest application of gum arabic and essential oils for controlling anthracnose and quality of banana and papaya during cold storage. *Postharvest Biology and Technology*, *62*(1), 71-76. https://doi.org/10.1016/j.postharvbio.2011.04.002

Martínez-Romero, D., Zapata, P. J., Guillén, F., Paladines, D., Castillo, S., Valero, D., & Serrano, M. (2017). The addition of rosehip oil to Aloe gels improves their properties as postharvest coatings for maintaining quality in plum. *Food Chemistry*, *217*, 585-592. https://doi.org/10.1016/j.foodchem.2016.09.035

Mendy, T. K., Misran, A., Mahmud, T. M. M., & Ismail, S. I. (2019). Application of *Aloe vera* coating delays ripening and extend the shelf life of papaya fruit. *Scientia Horticulturae*, *246*, 769-776. https://doi.org/10.1016/j.scienta.2018.11.054

Mohammadi, A., Hashemi, M., & Hosseini, S. M. (2016). Integration between chitosan and *Zataria multiflora* or *Cinnamomum zeylanicum* essential oil for controlling Phytophthora drechsleri, the causal agent of cucumber fruit rot. *LWT-Food Science and Technology*, *65*, 349-356. https://doi.org/10.1016/j.lwt.2015.08.015

Moradinezhad, F., & Ranjbar, A. (2023). Advances in postharvest diseases management of fruits and vegetables: A review. *Horticulturae*, *9*(10), 1099. https://doi.org/10.3390/horticulturae9101099

Mostafidi, M., Sanjabi, M. R., Shirkhan, F., & Zahedi, M. T. (2020). A review of recent trends in the development of the microbial safety of fruits and vegetables. *Trends in Food Science & Technology*, *103*, 321-332. https://doi.org/10.1016/j.tifs.2020.07.009

Motamedi, E., Nasiri, J., Malidarreh, T. R., Kalantari, S., Naghavi, M. R., & Safari, M. (2018). Performance of carnauba wax-nanoclay emulsion coatings on postharvest quality of 'Valencia' orange fruit. *Scientia Horticulturae*, *240*, 170-178. https://doi.org/10.1016/j.scienta.2018.06.002

Nair, M. S., Saxena, A., & Kaur, C. (2018). Effect of chitosan and alginate based coatings enriched with pomegranate peel extract to extend the postharvest quality of guava (*Psidium guajava* L.). *Food chemistry*, *240*, 245-252. https://doi.org/10.1016/j.foodchem.2017.07.122

Nasiri, M., Barzegar, M., Sahari, M. A., & Niakousari, M. (2017). Tragacanth gum containing *Zataria multiflora* Boiss. essential oil as a natural preservative for storage of button mushrooms (*Agaricus bisporus*). *Food Hydrocolloids*, *72*, 202-209. https://doi.org/10.1016/j.foodhyd.2017.05.045

Navarro, D., Díaz-Mula, H. M., Guillén, F., Zapata, P. J., Castillo, S., Serrano, M., Valero, D., & Martínez-Romero, D. (2011). Reduction of nectarine decay caused by *Rhizopus stolonifer*, *Botrytis cinerea* and *Penicillium digitatum* with *Aloe vera* gel alone or with the addition of thymol. *International Journal of Food Microbiology*, *151*(2), 241-246. https://doi.org/10.1016/j.ijfoodmicro.2011.09.009

Oliveira, D. G. P., Pauli, G., Mascarin, G. M., & Delalibera, I. (2015). A protocol for determination of conidial viability of the fungal entomopathogens Beauveria bassiana and Metarhizium anisopliae from commercial products. *Journal of Microbiological Methods*, *119*, 44-52. https://doi.org/10.1016/j.mimet.2015.09.021

Panchal, N., Das, K., Prabhakar, P. K., & Ghanghas, N. (2022). Edible films and coatings for fruits and vegetables: Composition, functions, and regulatory aspects. *Edible Food Packaging:*

Applications, Innovations and Sustainability, 191-216. https://doi.org/10.1007/978-981-16-2383-7_10

Pandey, A., & Singh, S. (2016). Aloe Vera: A Systematic Review of its Industrial and Ethno-Medicinal Efficacy. *International Journal of Pharmaceutical Research & Allied Sciences*, *5*(1), 1-21.

Rahimi Kakolaki, M., Omidi, A., Rasooli, A., & Shekarforoush, S. S. (2024). *In vitro* antifungal activity of barberry fruit extract (*Berberis* spp.) against *Fusarium* spp.. *Journal of Horticulture and Postharvest Research*, *7*(Special Issue - Postharvest Technologies), 47-60. http://dx.doi.org/10.22077/jhpr.2023.6783.1333

Ramezanian, A., Azadi, M., Mostowfizadeh-Ghalamfarsa, R., & Saharkhiz, M. J. (2016). Effect of *Zataria multiflora* Boiss and *Thymus vulgaris* L. essential oils on black rot of 'Washington Navel' orange fruit. *Postharvest Biology and Technology*, *112*, 152-158. https://doi.org/10.1016/j.postharvbio.2015.10.011

Rehman, M. A., Asi, M. R., Hameed, A., & Bourquin, L. D. (2020). Effect of Postharvest application of *Aloe vera* gel on shelf life, activities of anti-oxidative enzymes, and quality of 'Gola' guava fruit. *Foods*, *9*(10), 1361. https://doi.org/10.3390/foods9101361

Shehata, S. A., Abdeldaym, E. A., Ali, M. R., Mohamed, R. M., Bob, R. I., & Abdelgawad, K. F. (2020). Effect of some citrus essential oils on post-harvest shelf life and physicochemical quality of strawberries during cold storage. *Agronomy*, *10*(10), 1466. https://doi.org/10.3390/agronomy10101466

Singleton, V. L., & Rossi, J. A. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American journal of Enology and Viticulture*, *16*(3), 144-158.

Synowiec, A., Gniewosz, M., Kraśniewska, K., Przybył, J. L., Bączek, K., & Węglarz, Z. (2014). Antimicrobial and antioxidant properties of pullulan film containing sweet basil extract and an evaluation of coating effectiveness in the prolongation of the shelf life of apples stored in refrigeration conditions. *Innovative Food Science & Emerging Technologies*, *23*, 171-181. https://doi.org/10.1016/j.ifset.2014.03.006

Supa, S., Howlader, P., Ali, M., Rupa, R., & Bose, S. (2024). Edible coatings maintained postharvest quality and increased shelf life of guava fruits. *Journal of Horticulture and Postharvest Research*, *7*(Special Issue - Postharvest Technologies), 15-34. https://doi.org/10.22077/jhpr.2023.6531.1324

Thakur, R., Pristijono, P., Golding, J. B., Stathopoulos, C. E., Scarlett, C. J., Bowyer, M., & Vuong, Q. V. (2018). Development and application of rice starch based edible coating to improve the postharvest storage potential and quality of plum fruit (*Prunus salicina*). *Scientia Horticulturae*, *237*, 59-66. https://doi.org/10.1016/j.scienta.2018.04.005

Valero, D., Díaz-Mula, H. M., Zapata, P. J., Guillén, F., Martínez-Romero, D., Castillo, S., & Serrano, M. (2013). Effects of alginate edible coating on preserving fruit quality in four plum cultivars during postharvest storage. *Postharvest Biology and Technology*, *77*, 1-6. https://doi.org/10.1016/j.postharvbio.2012.10.011

Zapata, P. J., Navarro, D., Guillén, F., Castillo, S., Martínez-Romero, D., Valero, D., & Serrano, M. (2013). Characterisation of gels from different Aloe spp. as antifungal treatment: Potential crops for industrial applications. *Industrial Crops and Products*, *42*, 223-230. https://doi.org/10.1016/j.indcrop.2012.06.002