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The effect of *Aloe vera* gel and fennel (*Foeniculum vulgare*) essential oil on qualitative characteristics of apples during storage

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ABSTRACT

The aim of this study was to use edible coating of *Aloe vera* gel (AVG) with fennel essential oil (FEO) to increase shelf life and maintain qualitative characteristics of apples. Therefore, the present study was performed to investigate the effect of *Aloe vera* gel (at a concentration of 50%) and different levels of fennel essential oil (0, 500, and 1000 ppm) on some qualitative and sensory characteristics of apples fruit during three storage period (1, 10, 20, and 30 days) was conducted as a factorial experiment in a randomized complete base design with 3 replications. In each storage period, weight loss percentage, total soluble solids (TSS), titratable acidity (TA), sensory evaluation, color, and pH were examined. The results showed that the highest weight loss was related to the control treatment (without *Aloe vera* gel and essential oil) and the lowest weight loss was related to the treatment with 50% AVG + 1000 ppm FEO on days 10, 20 and 30 ($P<0.05$). The highest TSS and pH were observed in the control treatment on days 10, 20 and 30 ($P<0.05$). The lowest TA was observed in the control and AVG coated treatments on days 10, 20 and 30 ($P<0.05$). All coated treatments had higher taste index and yellowness index (a) during different days of storage compared to the control treatment ($P<0.05$). The findings of this study showed that *Aloe vera* gel (50%) and fennel essential oil (500 and 1000 ppm) can be effective as edible coatings to increase shelf life and maintain qualitative characteristics of apple fruit at 4°C.

1- Introduction

Apple (*Mauls domestica*) is one of the most nutritious fruits with high content of fiber, total soluble solids, organic acids, vitamins, polyphenols and antioxidants and is one of the most consumed fruits worldwide [1]. The production of apple fruit (86 million tons) ranks second in the world after banana (120 million tons) [2]. This shows that apple is an economically important crop. However, one of the main issues related to its commercialization is the rapid aging that occurs during post-harvest storage due to respiratory behavior and ethylene (C_2H_4) production, which makes apple, like most fruits, highly perishable and consequently reduces its shelf life [3].

The use of edible plant coatings containing natural antimicrobial compounds is a suitable method to control microbial growth and subsequently maintain the quality and shelf life of fresh fruits. Among edible coatings, aloe vera gel has been widely used as a natural preservative with antioxidant and antimicrobial properties to maintain the quality characteristics and increase the storage time of several fresh products [4, 5, 6]. Aloe vera (*Aloe barbadensis* Miller) is a perennial, drought-resistant succulent plant from the *Liliaceae* family [7]. Aloe vera gel has attracted the attention of researchers due to its cost-effectiveness, availability, and environmental friendliness [8]. The antioxidant and antimicrobial properties of aloe vera are due to the presence of bioactive compounds such as aloin, aloic acid, aloe-emodin, anthranol, isobarbaloin, barbaloin, cinnamic acid ester, and emodin. These compounds can effectively increase the shelf life of foods and make it the best option for food coatings [4, 9]. Aloe vera gel is odorless, transparent, edible, non-sticky, highly absorbent, safe for human health, and environmentally friendly [10]. Aloe vera gel coating has been reported to delay post-harvest browning and maintain some quality characteristics of harvested apple fruit (weight loss, titratable acidity, Brix, color, sensory evaluation, and pH) [8, 11].

Fennel, scientifically known as *Foeniculum vulgare* L., is a plant of the Apiaceae family that is cultivated worldwide for its aromatic seeds and leaves and is rich in essential oil (up to five percent) [12, 13]. Fennel essential oil is a clear, pale yellow liquid, and its main components include trans-anisole (about 65 to 78%). Fennel essential oil also contains alpha-pinene, terpene, geraniol, alpha-furanene, and limonene, which have good bacteriostatic effects against *E. coli*, *Bacillus subtilis*, and *Staphylococcus aureus* [13, 14, 15]. According to many studies, treating fruits with various plant essential oils increases shelf life, slows down weight loss, reduces spoilage, preserves fruit color, maintains firmness, and preserves soluble sugars in the fruit. Various studies reported that the use of fennel essential oil coating increased shelf life and preserved some quality properties of apples [16] and blueberries [17]. Therefore, in the present study, the effects of edible coating of Aloe vera gel with and without fennel essential oil were investigated on the quality characteristics of apple fruit after harvest at a temperature of 4°C during 30 days of storage.

2- Materials and Methods

2-1- Preparation of Fennel Essential Oil

Fennel plant was collected in the summer from the Sardoiyeh district of Jiroft city, Kerman province and dried at room temperature (25˚C) and in the shade. Then, a certain amount of the dried plant was ground and the essential oil was extracted by steam distillation using a Clevenger apparatus for three hours [18]. The resulting essential oil, after filtering and dehydration using sodium sulfate (Merck, Germany), was stored in dark glass containers in a closed container at a temperature of 4˚C until use.

2-2- Preparation of Aloe Vera Gel

Mature and fresh leaves of Aloe Vera plant were obtained from the research farm of Jiroft University and washed with distilled water. Then, the tip, end and serrated edges were cut

using a sharp knife. The skin and leaves were separated from the middle flesh of the leaf (gel). After separation of the gel components in an blender (Arshia, BL118-2290, Germany), it was homogenized and finally the resulting extract was filtered [19]. The concentration under investigation (50% w/w) was prepared by adding sterile distilled water to the pure gel.

2-3- Application of treatments

Golden Delicious apple fruit was obtained from Jiroft city and transferred to the Food Industry Laboratory of Jiroft University. The fruits were selected for this experiment based on the absence of physical damage, fungal rot and uniformity in terms of size, shape and color. The fruits were completely dried after washing. To coat the fruits, they were immersed in Aloe Vera gel (50% w/w) with different concentrations of fennel essential oil (0, 500 and 1000 ppm) for 5 min, and fruits washed with distilled water were used as control. The fruits were then placed in a colander to drain the water. The samples were dried by natural air flow for one hour at 25°C. Finally, they were stored in closed low-density polyethylene containers in a refrigerator at 4°C and 75% relative humidity [20]. The relevant tests were performed on them at ten-day intervals (1, 10, 20 and 30 days of age).

2-4- Measurement of weight loss

To measure weight loss, fruits of each treatment (three replicates each) were weighed separately at specified time intervals (1, 10, 20 and 30 days) using a digital scale (A&D, GF-3000, Japan) and then the percentage of weight loss was calculated using the following equation [8]:

percentage of weight loss = [initial weight/(secondary weight - initial weight)] ×100

2-5- Total soluble solids

The amount of soluble solids of control and treated fruits was estimated using a digital refractometer (Ezdo, DR-102, Taiwan). Distilled water was used to calibrate the refractometer. Two drops of fruit juice were poured onto the refractometer lens and after putting the cap on, its value was expressed in terms of Brix. This method was repeated three times for each fruit sample and after each measurement, its lens was cleaned with ethanol [21].

2-6- Titratable acidity

Titration method was used to measure titratable acidity. For this purpose, 10 ml of fruit juice was poured into an Erlenmeyer flask and then made up to volume with 20 ml of distilled water, and then two drops of phenolphthalein reagent (Merck, Germany) were added to it. The resulting solution was titrated using 0.1 normal sodium hydroxide (Merck, Germany) until a purple color appeared. The titratable acidity was expressed in terms of percentage of malic acid (the dominant acid in apple fruit) [19].

2-7- pH measurement

The pH of the fruit juice was measured using a pH meter (Sartorius, Professional Meter PP-50, Germany) calibrated with standard buffers (pH= 4.01, pH= 7.00, pH= 10.01) [4].

2-8- Sensory evaluation

In this evaluation, 8 students and professors of Jiroft University who were trained to be familiar with this method were used as evaluators. Sensory evaluation was performed at the end of the storage period (30 days) using a 5-point hedonic method. In this evaluation, 5 indicated very good, 4 indicated good, 3 indicated average, 2 indicated poor, and 1 indicated very poor. The evaluators were asked to evaluate the apple samples in terms of color, odor, taste, texture, and overall acceptability [22].

2-9- Color index

The apparent color of the fruit was measured using a colorimeter (TES-135A, TES, Taiwan). The results were expressed as L* (luminance), a* (red-green), and b* (yellow-blue). In this study, the average data of each experiment in three replicates was used [4].

2-10- Statistical analysis

Statistical analysis of the data was performed based on a factorial design in a completely randomized design with three replicates. Comparison of means was performed using one-way ANOVA and Duncan's multiple

range test at a statistical level of five percent using SPSS 27 statistical software.

3-Results and Discussion

3-1- Weight Loss

The effect of coating treatment, storage time and the interaction effect of treatment and time on changes in fruit weight loss are shown in Table 1. The results showed that the effect of treatments on weight loss was significant ($P<0.05$), such that the amount of weight loss during storage was increasing and the lowest percentage of weight loss was related to the Aloe Vera coating treatment 50% + 1000 ppm fennel essential oil, and the uncoated treatment had the highest weight loss compared to other treatments ($P<0.05$). Based on the results of the storage time study, the percentage of weight loss increased during the three storage periods and in all treatments, and this increase was more in the uncoated treatment than in the other treatments ($P<0.05$). The lowest percentage of weight loss was observed on the tenth day for the Aloe Vera coating treatment 50% + 1000 ppm fennel essential oil, and the highest percentage of weight loss was observed on the thirtieth day for the uncoated treatment ($P<0.05$).

Fruit weight loss is considered a major factor in determining the quality and marketability of fruit and is increased due to various metabolic processes including respiration and transpiration. In one study, an increase in weight loss was observed in uncoated strawberries with increasing storage time [23]. In another experiment, it was reported that fig fruit weight loss increased with increasing storage time and that coating with anthocyanin-enriched aloe vera gel maintained weight [21]. The results of one study indicated that strawberries coated with aloe vera gel (20%) had less weight loss compared to the uncoated treatment, which is consistent with the results of the present study [24]. This effect may be due to the polysaccharides present in aloe vera gel, which allows the formation of a physical barrier for protection. Also, in another experiment, the effect of different levels of aloe vera gel coating (0, 15, 30, 45 and 60%) and chitosan (0, 0.5, 1, 1.5 and 2%) on the shelf life of tomatoes was investigated and it was reported that the coated treatments had less weight loss compared to the uncoated treatment [6]. It has been reported that the use of two coatings of fennel essential oil and beta-cyclodextrin caused the weight of blueberry fruit to be preserved compared to the uncoated treatment (storage days 2, 4 and 8) [17]. In another experiment, the effect of nanoliposomal coating containing cinnamon essential oil on the post-harvest quality of apple fruit was investigated and it was reported that the uncoated treatment had more weight loss compared to the coated treatments on days 3, 6, 9, 12 and 15 of storage [25]. Edible coatings containing plant extracts, due to their antimicrobial and antifungal properties, help protect the product against pathogens and consequently reduce decay, and thus can prevent water loss and fruit weight loss [23]. According to the results of the present study, the ability to reduce weight loss of the samples increased with increasing concentration of fennel essential oil in the aloe vera gel coating. This may be due to the creation of permeability between the apple surface and the edible coating, which helps reduce the rate of respiration and water loss.

Table 1. Weight loss changes (%) in the control and coated apples with *Aloe vera* gel (AVG) and fennel essential oil (FEO) during storage at 4°C

Treatments/ Storage time	Day 1	Day 10	Day 20	Day 30
Control	0.00^{Da}	1.80 ± 0.05^{Ca}	3.38 ± 0.08^{Ba}	4.67 ± 0.10^{Aa}
50% AVG	0.00^{Da}	1.17 ± 0.03^{Cb}	2.43 ± 0.06^{Bb}	3.11 ± 0.08^{Ab}
50% AVG + 500 ppm FEO	0.00^{Da}	1.02 ± 0.03^{Cc}	1.96 ± 0.02^{Bc}	2.57 ± 0.09^{Ac}
50% AVG + 1000 ppm FEO	0.00^{Da}	0.97 ± 0.01^{Cc}	1.47 ± 0.05^{Bd}	2.17 ± 0.07^{Ad}

Means with different letters are significantly different at $P<0.05$ using Duncan's test. Similar letters = not significant.
Different lowercase letters denote significant differences ($P<0.05$) among different treatments for the same sampling time.
Different capital letters denote significant differences ($P<0.05$) among different sampling times for the same treatment.

3-2- Total soluble solids

The changes in soluble solids in treated and control apples during storage are presented in Table 2. The amount of soluble solids increased during storage in all treatments ($P<0.05$). However, this increase was significantly greater in the control treatment ($P<0.05$). Overall, the amount of soluble solids increased during storage in uncoated fruits from 12.67° Brix on day 1 to 18.67° Brix on day 30 ($P<0.05$). During different storage periods, all coated treatments had the lowest amount of soluble solids changes compared to the uncoated treatment, and the lowest amount was related to the treatment with Aloe vera 50% + 1000 ppm fennel essential oil ($P<0.05$). Soluble solids and titratable acidity determine the eating quality and overall acceptability of the fruit. The soluble solids content of the samples is mainly composed of soluble sugars and organic acids, and their composition indicates the maturity, flavor, and physiological changes of the fruit. Since soluble solids constitute 75% of the sugars, the increase in soluble solids during storage may be due to the conversion of starch to sugars caused by high respiration. Also, fruit respiration and aging cause the breakdown of cell wall polysaccharides and their conversion to simpler compounds [17, 26]. Another reason for the increase in solids during storage is the loss of water and the increase in the concentration of the fruit juice content. The increase in soluble solids during storage is due to the accumulation of glucose as a result of the hydrolysis of carbohydrates, which is faster than the process of converting glucose to energy and H2O [27]. In one study, an increase in soluble solids was observed during storage [21]. Shafique et al. [24] reported that a 20% aloe vera gel coating preserved the total soluble solids content of strawberries during storage by reducing respiration rate and ethylene production. In one study, an increase in the soluble solids content of cherry fruit was observed during 28 days of storage and it was reported that the use of aloe vera gel and thymol coating preserved it [22]. The results of one study indicated that the soluble solids content of tomatoes in uncoated samples increased during storage, but its content in samples coated with aloe vera gel changed slightly during storage [4]. Aloe vera gel-based edible coatings can delay the ripening process of fruits by slowing down the rate of reactions that produce complex compounds and increase soluble solids [4, 24]. In another experiment, the effect of fennel essential oil and β-cyclodextrin coatings on the total soluble solids content of blueberry fruit during storage was investigated. The results of that experiment showed that all treatments increased the total soluble solids content and decreased over time, but the changes were more evident in the uncoated group, and they stated that this behavior could be due to the fact that the fruits in the control group showed a higher respiratory rate [17]. It seems that the favorable effect of the aloe vera gel and fennel essential oil coating on the slight changes in the total soluble solids content during the storage period is related to the reduction of evaporation and transpiration from the fruit surface as well as the reduction of respiration rate.

Table 2. Total soluble solids changes (%) in the control and coated apples with *Aloe vera* gel (AVG) and fennel essential oil (FEO) during storage at 4°C

Treatments/ Storage time	Day 1	Day 10	Day 20	Day 30
Control	12.67 ± 0.70^{Ca}	15.33 ± 1.08^{Ba}	19.33 ± 1.20^{Aa}	18.67 ± 1.00^{Aa}
50% AVG	12.33 ± 0.50^{Ca}	14.33 ± 0.90^{Bb}	15.67 ± 1.10^{Ab}	14.67 ± 0.70^{ABb}
50% AVG + 500 ppm FEO	12.67 ± 0.80^{Ca}	13.67 ± 0.90^{Bbc}	14.67 ± 1.10^{Abc}	14.00 ± 1.01^{ABbc}
50% AVG + 1000 ppm FEO	12.33 ± 0.70^{Ca}	13.00 ± 0.80^{BCc}	14.33 ± 0.80^{Ac}	13.67 ± 0.70^{ABc}

Means with different letters are significantly different at $P<0.05$ using Duncan's test. Similar letters = not significant.
Different lowercase letters denote significant differences ($P<0.05$) among different treatments for the same sampling time.
Different capital letters denote significant differences ($P<0.05$) among different sampling times for the same treatment.

3-3- Titratable Acidity

Table 3 shows the changes in acidity percentage in coated and uncoated apples during different storage periods. Experimental treatments and time had a significant effect on the acidity percentage of the fruit ($P<0.05$). The results showed that the acidity of coated and uncoated samples decreased during different days of storage ($P<0.05$). And the acidity of the uncoated treatment decreased from 0.37% on day 1 to 0.27% on day 30 ($P<0.05$). The lowest acidity changes were related to the treatment of 50% Aloe Vera coating + 500 ppm Fennel essential oil and 50% Aloe Vera coating + 1000 ppm Fennel essential oil on days 20 and 30 of storage ($P<0.05$).

Usually, during the storage period of fruits, the amount of organic acids decreases and the pH increases, which can be due to the consumption of organic acids such as malic and citric acid (the primary substrate in the respiration process) [28]. Also, the amount of organic acids decreases during fruit storage due to consumption in the respiration processes and conversion to sugar, and the amount of these acids indicates the metabolic activity of the tissue [24]. It has been shown that the percentage of titratable acidity in uncoated strawberries decreased with the passage of storage time [23]. The results of a study indicate that coating fresh figs with aloe vera gel enriched with edible anthocyanins caused a decrease in the percentage of acidity during the storage period, but this decrease was greater in the control treatment [21]. Researchers investigated the effect of alginate coating with Spirulina platensis microalgae, Aloe vera gel and guar gum on the physicochemical properties of mango fruit during cold storage and reported that the percentage of acidity decreased in all treatments during four weeks of storage, but this decrease was more evident in the uncoated treatment [29]. It has been reported that the use of Aloe vera gel coating (33%) and thymol caused slight changes in the acidity of Duke cherry fruit during a 28-day storage period, which could be due to the reduction in respiration rate and water loss by these coatings [22]. The results observed in the coating treatments may be due to the impermeable nature of oxygen and carbon dioxide molecules and the modified atmosphere around the fruits, which reduces respiration and preserves organic acids [24]. In addition, phenols and compounds present in plant extracts and essential oils help reduce respiration and ethylene production, and overall reduce the rate of metabolic processes and the consumption of organic acids [23, 24, 30].

Table 3. Titratable acidity changes (%) in the control and coated apples with *Aloe vera* gel (AVG) and fennel essential oil (FEO) during storage at 4°C

Treatments/ Storage time	Day 1	Day 10	Day 20	Day 30
Control	0.37 ± 0.02^{Aa}	0.36 ± 0.01^{Ba}	0.32 ± 0.02^{Cb}	0.27 ± 0.01^{Dc}
50% AVG	0.36 ± 0.02^{Aa}	0.35 ± 0.03^{Ab}	0.32 ± 0.01^{Bb}	0.30 ± 0.02^{Cb}
50% AVG + 500 ppm FEO	0.37 ± 0.01^{Aa}	0.36 ± 0.01^{Aa}	0.34 ± 0.03^{Ba}	0.32 ± 0.01^{Ca}
50% AVG + 1000 ppm FEO	0.36 ± 0.02^{Aa}	0.36 ± 0.02^{Aa}	0.34 ± 0.01^{Ba}	0.32 ± 0.01^{Ca}

Means with different letters are significantly different at $P<0.05$ using Duncan's test. Similar letters = not significant. Different lowercase letters denote significant differences ($P<0.05$) among different treatments for the same sampling time. Different capital letters denote significant differences ($P<0.05$) among different sampling times for the same treatment.

4-3- pH

The effect of different experimental treatments on pH is shown in Table 4. The results showed that the effect of coating treatment and storage time on pH was significant ($P<0.05$). So that pH increased during storage, and the uncoated treatment had the highest change compared to other treatments ($P<0.05$). In general, pH increased during storage in uncoated fruits from 4.50 on day 1 to 5.02 on day 30 ($P<0.05$).

As fruit ripening increases during storage, pH also increases due to the destruction of cell walls and organic acids, which leads to the release of soluble solids and glucose. In a

study, the effect of edible coatings of aloe vera gel (0, 30, and 45%) and carnauba wax microparticles (0, 0.3, and 0.4%) on the shelf life of strawberries was investigated and it was reported that the pH increased during different storage periods and this increase was greater in the uncoated treatment [31]. In an experiment, the effect of coating aloe vera gel enriched with edible anthocyanins on fresh figs was investigated and it was reported that the pH increased during storage in all treatments and the highest change was related to the uncoated treatment [21]. Researchers reported that the use of bergamot essential oil coating maintained the pH of strawberries during different storage periods and that the increase in pH in uncoated fruits during storage could be due to the consumption of organic acids during fruit ripening [30]. The increase in sugars and decrease in acids during storage in some fruits leads to an increase in pH [17, 31]. While in uncoated fruits, due to higher respiration, organic acids are broken down and consumed as substrates for respiratory enzymatic activities, resulting in a higher pH in control fruits [17]. Plant essential oils, by slowing down the consumption of organic acids during the enzymatic processes of respiration, reduce the rate of respiration, preserve organic acids, and thus maintain low pH levels [30].

Table 4. pH changes in the control and coated apples with *Aloe vera* gel (AVG) and fennel essential oil (FEO) during storage at 4°C

Treatments/ Storage time	Day 1	Day 10	Day 20	Day 30
Control	4.50 ± 0.10^{Db}	4.65 ± 0.09^{Ca}	4.88 ± 0.09^{Ba}	5.02 ± 0.09^{Aa}
50% AVG	4.52 ± 0.10^{Da}	4.56 ± 0.10^{Cb}	4.61 ± 0.10^{Bb}	4.67 ± 0.08^{Ab}
50% AVG + 500 ppm FEO	4.53 ± 0.11^{Da}	4.56 ± 0.07^{Cb}	4.59 ± 0.08^{Bc}	4.62 ± 0.10^{Ac}
50% AVG + 1000 ppm FEO	4.52 ± 0.09^{Da}	4.54 ± 0.08^{Cc}	4.56 ± 0.10^{Bd}	4.59 ± 0.11^{Ac}

Means with different letters are significantly different at $P<0.05$ using Duncan's test. Similar letters = not significant.
Different lowercase letters denote significant differences ($P<0.05$) among different treatments for the same sampling time.
Different capital letters denote significant differences ($P<0.05$) among different sampling times for the same treatment.

5-3- Sensory evaluation

According to Table 5, the use of aloe vera gel coating and fennel essential oil had no significant effect on the sensory evaluation results of apple color and aroma ($P>0.05$). However, the sensory evaluation results of taste, texture, and overall acceptance were affected by the experimental treatments ($P<0.05$), so that all experimental treatments received the highest sensory score for aroma and smell compared to the uncoated treatment ($P<0.05$). Also, the treatments of aloe vera coating 50% + 1000 ppm fennel essential oil and aloe vera coating 50% + 500 ppm fennel essential oil received the highest sensory score for texture and overall acceptance compared to other treatments ($P<0.05$).

The appearance and edible quality of the fruit decreases significantly during storage due to increased respiration and enzymatic activity of the fruit. In coated samples, overall acceptance was assessed as better due to reduced respiration and greater retention of fruit aroma and flavor compounds [23]. In an experiment, the effect of using aloe vera gel and orange peel essential oil coating on the sensory properties of button mushrooms was investigated and it was reported that the experimental treatments maintained sensory properties (color, texture, odor, appearance, and overall acceptance) compared to the control treatment [32]. Researchers reported that strawberries coated with citrus essential oil had higher sensory properties compared to the uncoated treatment [23]. It has been shown that blueberries coated with fennel essential oil and beta-cyclodextrin had better sensory properties compared to the uncoated treatment [17], which may be possible due to delayed microbial contamination, less weight loss, minimized oxidation, and maintained higher levels of antioxidant enzymes such as catalase and superoxide dismutase [23, 24, 32]. Aloe vera gel coating has been reported to have antimicrobial properties that reduce decay and

microbial attack and preserve fruit texture [8, 26].

Table 5. Sensory changes in the control and coated apples with *Aloe vera* gel (AVG) and fennel essential oil (FEO) during storage at 4°C

Treatments	Color	Odor	Taste	Texture	General acceptance
Control	3.50^{a}	3.25^{a}	3.00^{b}	3.37^{b}	3.56^{b}
50% AVG	3.62^{a}	3.62^{a}	3.93^{a}	4.00^{ab}	4.00^{ab}
50% AVG + 500 ppm FEO	4.00^{a}	3.93^{a}	4.18^{a}	4.43^{a}	4.44^{a}
50% AVG + 1000 ppm FEO	3.62^{a}	3.50^{a}	4.31^{a}	4.62^{a}	4.12^{ab}

Means with different letters are significantly different at P<0.05 using Duncan's test. Similar letters = not significant.
Different lowercase letters denote significant differences (P<0.05) among different treatments for the same sampling time.
Different capital letters denote significant differences (P<0.05) among different sampling times for the same treatment.

6-3- Color indices

Table 6 reports the results of the surface color of the fruits. Comparison of the means showed a significant difference during the storage period for the L*, a* and b* indices (P<0.05), with a decreasing trend over time. In the uncoated treatment, the coated treatments had the lowest L*, a* and b* indices (P<0.05). The L* index in the coated samples had higher values than the control, and the highest value was related to the treatment of aloe vera 50% + 1000 ppm fennel essential oil (P<0.05). Comparison of the means of a* and b* traits after the application of edible coatings containing aloe vera gel and fennel essential oil showed that the aforementioned coatings controlled the decreasing trend in apple fruits (P<0.05).

Color is one of the vital parameters in food products that indicates their sensory and quality characteristics. Based on the results, the color indices decreased with time and concomitant degradation of pigments under enzymatic and non-enzymatic reactions. It has been reported that the use of different edible coatings (moringa leaf extract, 20% aloe vera gel, oxalic acid and ascorbic acid) maintained the L*, a* and b* indices of strawberries compared to the uncoated treatment during the storage period [24]. In a study, researchers found that the use of aloe vera gel coating maintained the L*, a* and b* indices of tomatoes during 12 days of storage compared to the uncoated treatment [4]. Among the treatments, the 50% aloe vera coating + 500 ppm fennel essential oil had a lighter color (P<0.05), indicating the optimal concentration of fennel essential oil to protect the samples from color changes (Table 6). This can be attributed to the higher moisture content of the samples coated with aloe vera gel and fennel essential oil (500 ppm). When the concentration of essential oil is too high, it leads to cellular damage of apple tissue, which causes the samples to spoil [30]. This indicates that aloe vera-based fruit coatings delay the color change by delaying the ripening process [8, 29]. In fruits, with the passage of storage time due to respiration and increase in pH, their pigments decompose, and as a result, their color and appearance quality decreases [29, 30]. However, edible coatings containing essential oils and plant extracts play an important role in preserving the color of the fruit. Researchers found that phenolic compounds present in these plant compounds, having antioxidant properties, prevent the oxidation of plant pigments in cells during storage [24, 29]. Fallah et al. (2025) reported that a film prepared from gluten-carboxymethyl cellulose and sour tea anthocyanin preserved the color of salmon and prevented its spoilage during storage [33].

Table 6. Color changes in the control and coated apples with *Aloe vera* gel (AVG) and fennel essential oil (FEO) during storage at 4°C

Treatments Edible coating	Storage time (days)	L*	a *	b*
Control	1	67.77±1.18^{Aa}	-6.03±0.80^{Ba}	26.06±1.25^{Aa}
	10	59.28±1.22^{Bb}	-5.90±0.55^{Bb}	26.47±2.18^{Ab}
	20	54.83±1.48^{Cc}	-4.93±0.72^{Ac}	24.07±2.23^{Bb}
	30	52.02±2.08^{Dc}	-4.30±0.43^{Ac}	22.65±1.45^{Bb}
50% AVG	1	64.40±1.25^{Ab}	-6.36±0.29^{Ca}	26.28±1.28^{Ba}
	10	61.76±1.38^{Ba}	-5.51±0.22^{BCb}	26.82±1.56^{Bb}
	20	58.82±1.55^{Cb}	-4.62±0.10^{ABbc}	28.64±2.28^{Aa}
	30	54.24±1.39^{Db}	-3.85±0.50^{Ac}	29.79±1.51^{Aa}
50% AVG + 500 ppm FEO	1	62.95±2.42^{Ac}	-6.66±0.81^{Da}	26.60±2.44^{Da}
	10	58.82±2.18^{Bb}	-4.99±0.56^{Cab}	28.08±2.10^{Ca}
	20	62.13±1.29^{Aa}	-4.01±0.59^{Bb}	29.13±2.18^{Ba}
	30	59.75±1.71^{Ba}	-3.05±0.44^{Ab}	30.41±1.88^{Aa}
50% AVG + 1000 ppm FEO	1	59.18±1.18^{Ad}	-6.28±0.92^{Da}	26.57±2.18^{Ca}
	10	51.87±2.48^{Bc}	-4.70±0.38^{Ca}	28.45±2.16^{Ba}
	20	51.33±1.35^{Bd}	-2.74±0.57^{Ba}	29.91±1.58A^{Ba}
	30	58.13±1.44^{Aa}	-1.81±0.83^{Aa}	31.75±1.88^{Aa}

Means with different letters are significantly different at P<0.05 using Duncan's test. Similar letters = not significant.
Different lowercase letters denote significant differences (P<0.05) among different treatments for the same sampling time.
Different capital letters denote significant differences (P<0.05) among different sampling times for the same treatment.

4- Conclusion

The results of the present study showed that coating apple fruit with Aloe Vera gel along with fennel essential oil, as a suitable method, can play an important role in maintaining the quality and increasing the shelf life of apples at a temperature of four degrees Celsius. In this study, apple fruits coated with 50% Aloe Vera + 1000 ppm fennel essential oil had significantly less weight loss. The results of this study also showed that coating apple fruit using Aloe Vera gel along with fennel essential oil maintained the number of soluble solids, acidity, color index, texture index and taste, and pH compared to the uncoated treatment.

Data Availability

The data used to support the finding of this study are available from the corresponding author upon request.

Conflict Of Interest

The authors have no conflicts interest to report.

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تأثیر ژل آلوئه‌ورا و اسانس رازیانه بر ویژگی‌های کیفی سیب در طی دوره انبارداری

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چکیده

هدف از این مطالعه استفاده از پوشش خوراکی ژل آلوئه‌ورا همراه با اسانس رازیانه به‌منظور افزایش ماندگاری و حفظ ویژگی‌های کیفی سیب بود. در این پژوهش به‌منظور بررسی تأثیر ژل آلوئه‌ورا (در غلظت ۵۰ درصد) و اسانس رازیانه (سطوح صفر، ۵۰۰ و ۱۰۰۰ پی‌پی‌ام) بر برخی خصوصیات کیفی و حسی سیب در دمای چهار درجه سانتی‌گراد طی چهار دوره انبارداری (۱، ۱۰، ۲۰ و ۳۰ روز) آزمایشی به‌صورت فاکتوریل در قالب طرح کاملاً تصادفی با سه تکرار انجام شد. در هر دوره انبارداری افت وزن، مواد جامد محلول کل، اسیدیته قابل تیتراسیون، ارزیابی حسی، رنگ و pH مورد بررسی قرار گرفت. نتایج نشان داد که بیشترین میزان افت وزن مربوط تیمار بدون پوشش و کمترین میزان افت وزن مربوط به تیمار پوشش آلوئه‌ورا ۵۰ درصد +۱۰۰۰ پی‌پی‌ام اسانس رازیانه در روزهای ۱۰، ۲۰ و ۳۰ بود ($P<0.05$). بیشترین میزان مواد جامد محلول کل و pH در تیمار بدون پوشش در روزهای ۱۰، ۲۰ و ۳۰ مشاهده شد ($P<0.05$). کمترین میزان اسیدیته قابل تیتراسیون در تیمار بدون پوشش و پوشش آلوئه‌ورا در روزهای ۱۰، ۲۰ و ۳۰ مشاهده شد ($P<0.05$). تمامی تیمارهای پوشش داده شده در مقایسه با تیمار شاهد شاخص طعم و شاخص زردی (a) بالاتری در طی روزهای مختلف انبارداری داشتند ($P<0.05$). یافته‌های این پژوهش نشان داد که ژل آلوئه‌ورا (غلظت ۵۰ درصد) و اسانس رازیانه (غلظت ۵۰۰ و ۱۰۰۰ پی‌پی‌ام) می‌توانند به عنوان پوشش خوراکی جهت افزایش ماندگاری و حفظ ویژگی‌های کیفی میوه سیب در دمای چهار درجه سانتی‌گراد مؤثر باشد.