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RESEARCH

The Individual and Combined Effects of Electrolyzed Water and Chitosan Coating Applications on the Storage Stability of Fresh Strawberries

Nesrin Yumak Alnıak[1] · Cengiz Caner[1] · Muhammed Yüceer[2]

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Abstract
Fresh strawberry is very susceptible to spoilage and has limited storage stability due to its fast metabolism. The main focus of this research was to evaluate if electrolyzed water (EW) (30 ppm or 90 ppm) and 1% chitosan coating can be applied individually and in combination to evaluate individual and synergistic effects on extending the storage stability of fresh strawberries. The samples were analyzed (the gas composition, pH, ºBrix, weight loss, spoilage rate, texture as well as total anthocyanin and total phenolic composition) for the 5 weeks at 4 ºC. At the end of storage, the O_2 in the trays reduced from 21 to 13% in the groups treated with chitosan, and the CO_2 ratio increased from 0.03 to 14%. The most dramatic change in gas exchange, pH, and ºBrix occurred in the control group during storage. The decrease was less in the chitosan-coated ones. Although there is no linear change in color values (L^* and a^*), it can be said that EW application has a more conservative feature, especially on "a^*". At the end of the storage, the combination of chitosan and EW had a spoiled fruit rate of 25–30% by weight, while this rate reached 67% in the control group. The hardness value of strawberries decreases throughout storage. Although there was a decrease in total anthocyanin and total phenolic components during the 5 weeks of storage, the highest protection was measured in samples where chitosan and EW were applied together. As a result of this study, the remarkable synergistic efficacy carried out by the combined application of the chitosan coatings and the EW (30 ppm or 90 ppm) makes it an attractive promising sustainable substitute for artificial preservatives while maintaining their fresh-like quality and improved appeal within the food industry.

Keywords Electrolyzed water · Chitosan coatings · Fresh strawberries · Sustainable postharvest technology · Storage stability

Introduction

Food consumption and purchasing have been majorly changing by the transformation of lifestyles over time. Moreover, consumers demand fresh fruits that are natural, less processed, and additive-free foods with high quality and reduce food loss. In harvested fresh produce, the metabolic process continues to result in deterioration (Caleb et al., 2013; Caner et al., 2025a) thus helping in keeping high quality and is essential for extending store stability for enhancing the sustainability (Opara & Mditshwa, 2013).

Fresh strawberry is a unique and popular fruit with an attractive color and highly desirable taste and aroma and is a good source of bioactive compounds (vitamin C, anthocyanins, and polyphenols). Fresh strawberry consumption has increased in the last decades due to its nutritional values and health benefits. According to FAO data, its production has increased by 39% in the last 10 years in order to meet global demand. Fresh strawberry (*Fragaria* sp.) is a berry-like fruit that can be widely produced almost anywhere in the world (Caner et al., 2025b). Fresh strawberries are a highly perishable produce that is susceptible to fast softening and mold growth. It is very important to develop fresh fruit and vegetable preservation techniques, reduce significant post-harvest

✉ Cengiz Caner
ccaner@comu.edu.tr

Muhammed Yüceer
myuceer@comu.edu.tr

1 Department of Food Engineering, Canakkale Onsekiz Mart University, 017020 Canakkale, Turkey

2 Department of Food Processing, Canakkale Onsekiz Mart University, 017020 Canakkale, Turkey

losses, and enhance the storage stability to deliver to the consumer in high quality (Jadhav & Choudhary, 2024).

The non-thermal technology applications in sustainable food processing have been found as an alternative to thermal treatments to extend the high quality and storage stability of perishable foods (Jadhav & Choudhary, 2024). Various processes such as edible coatings, ultraviolet light (UV), sonication (US), and ozone and high hydrostatic pressure (HHP) are commercially available, and many more processes such as electrolyzed water (EW) are aimed at extending the fruit life of post-harvest operations to reduce the rate of respiration and loss of water, preserve the firmness of the fruit, and restrict microbial growth (Allai et al., 2023).

One such technique gaining attention is EW, favored for its sustainability, being cheap, availability, and ease of utilization in fruit and vegetable preservation. The usage of EW has been increased recently in the food industry as a feasible alternative to standard chlorine sanitizers for minimizing or eliminating microbial diversity in perishable foods (Ahmed et al., 2022). EW, one of the newest preservation technologies, is used in the fruit and vegetable sectors not only as a new disinfectant, but also in improving the storage stability of fresh produce with inhibiting common microorganisms (Feliziani et al., 2016). It has been commonly accepted as a browning inhibitor in several fresh-cut produce, such as fresh-cut apples and others (Luo et al., 2024), and also in inhibiting microbial multiplication, maintaining their high nutritional quality and firmness (Zhang et al., 2021). EW, produced in an electrolyze chamber containing dilute salt (NaCl) or HCl solution, attracts attention as a disinfectant with increasing use because of its antimicrobial activity against a wide variety of microorganisms in a short time. EW disrupts bacterial cell walls by aiming at oligopeptides, causes change in protein structures, and increases the permeability of cell membranes. Once inside the cell, EW interacts with DNA, inducing conformational changes that significantly affect nucleotide metabolism, inhibiting energy-related processes, amino acid biosynthesis, and osmotic regulation and stimulating fatty acid metabolism, ultimately leading to bacterial apoptosis (Wang et al., 2023). Although, the utilization of EW in food protection mostly concentrate on the microbial control of poultry (Wang et al., 2018), meat (Liao et al., 2020), seafood, fruits and vegetables (Chen et al., 2017, 2020), and fresh-cut products (Gao et al., 2022; Mohajer et al., 2023).

Utilization of the optimized EW in fresh berry preservation improved phenolic and anthocyanin contents during storage but had minimal effect on overall quality (Caner et al., 2025b). For that reason, other preservation techniques such as biocoating must be combined to improve the storability of fresh berries. Polysaccharide-based edible biocoating such as chitosan is one of bright substances due to its favorable oxygen barrier, nontoxicity properties, biocompatibility, and antimicrobial activity (Caner et al., 2023b, 2025a; Iqbal et al., 2023; Yuceer & Caner, 2014; Zhao et al., 2021). Chitosan, derived from renewable sources, is a cost effective polymer that provides endless structural possibilities for chemical and mechanical modifications that can create innovative superior properties, applications, and functions such as its ability to form a thin layer (film) on the fruit surface and prevent moisture and aroma loss (Xing et al., 2016; Zhang et al., 2022).

Due to the strategic market, researchers use advanced techniques such as sustainable chitosan biocoating to preserve perishable fresh berries for a longer period. Depending on the variety of fruits, biocoating substances may have various extents of efficacy. The aim of bio-coatings is to play a major role in fresh strawberries in controlling the mass transfer of gases (O_2/CO_2), flavorings, moisture, and other dissolved compounds (Pham et al., 2023). Since sustainable chitosan biocoatings are safe and environmentally friendly, they attract attention as an increasingly important post-harvest preservation technology in slowing down the spoilage of fresh produce and increasing their store stability (Dai et al., 2020; Latifasari et al., 2019). Since it provides a protective layer on the outer surface of the fresh fruit, it has the potential of minimizing gas exchange of the fruit, thereby slowing down the rate of respiration and production of ethylene and also spoilage of the food it is coated with and enhance its shelf life (Zhang et al., 2022).

Apart from preservation techniques, they use some chitosan coatings, which have a very important role in fruit softening, delaying fruit rot, maintaining increased ascorbic acid and phenol levels, increasing the activities of antioxidant enzymes, and reducing membrane damage (Huma Qureshi et al., 2023). There are several techniques used to enhance the postharvest quality of fresh strawberry including modified atmosphere packaging, gamma irradiation, coatings, or EW (Ahmed et al., 2022; Larrigaudière et al., 2009).

Enhanced storage stability periods for fresh produce such as fruit are demanding due to their very perishable nature. EW is extensively accepted as a sustainable disinfection agent that has been presented in several researches as an efficacious sanitizer for lowering microbial load and enhancing the storage stability of fresh produce (Ahmed et al., 2022; Du et al., 2024). Caner et al. (2025b) highlighted that applying chitosan coatings to postharvest fresh berries considerably reduced fruit degradation and enhanced overall postharvest quality, enhancing the storage stability. Even though EW and chitosan coatings seem to be promising disinfectants, their usage alone can sometimes be ineffectual in limiting the growth of bacteria on the fresh produce. In order to enhance disinfection performance and broaden antimicrobial activity, a synergistic approach of EW with other methods is required to generate a combined impact where each treatment will show lower intensities throughout the consecutive or simultaneous process (Ahmed et al., 2022).

However, there is insufficient research paper on observing the impact of chitosan coatings in conjunction with EW application on the storage stability of "fresh strawberry" during extended storability. As per our knowledge, there is no present paper on the combined utilization of chitosan (1%) and EW (30 and 90) treatment for fresh fruits such as berry preservation. The main aim of this research was to provide novel insights into mitigating the enhancing storage stability of berry, presenting innovative sustainable approaches.

Material and Methods

Materials

Fresh strawberries were obtained from local producers in Çanakkale, Turkey. Fresh berries were selected based upon the similar size, surface < color, and absence of any fruit deformity before treatments.

Preparation of Electrolyzed Water

EW was produced by the electrolyzed water generator (MIOX Corporation, New Mexico, USA) apparatus using NaCl (1%). After the electrolysis process of the brine solution inside the equipment, EW was obtained from the mixture of anode and cathode solution in a receiving vessel (Hayta & Aday, 2015). The harvested fresh strawberry was exposed to electrolyzed water (30 and 90 ppm) for 1 min.

Preparation of Chitosan Coating

The coating solutions were prepared by dissolving the chitosan (1%w/w) in acetic acid (1%) with the addition of glycerol as plasticizer (0.25%, w/w) (Caner et al., 2022). The samples were immersed in the chitosan solution (1 min), left on Al foil (10 min), then immersed (1 min) one more time, then left to dry at 24 °C for 1 h (Atakan et al., 2025).

Application groups and application parameter:

1. Control
2. Chitosan 1% coating
3. 30 ppm electrolyzed (EW) water (1 min)
4. 90 ppm electrolyzed (EW) water (1 min)
5. 30 ppm electrolyzed (EW) water (1 min) and 1% chitosan coating
6. 90 ppm electrolyzed (EW) water (1 min) and 1% chitosan coating

After application, the fresh strawberries were packed in PVC-PE trays (13 × 20 × 7 cm) as 180 g and then the heat-sealed by a packing machine (MAP-25, Apack A.S., Istanbul, Turkey) with antifog microperforated lid PP films (30-µm thickness with 3-hole 90-µm diameter) (Korozo Co. R&D, Istanbul, Turkey) and stored in a cold room (4 °C with a relative humidity of 85 ± 5%) during storage period.

The analyses of this study were carried out in two replicates and in parallel in the 1st, 2nd, 3rd, 4th, and 5th weeks of storage.

Measurements

Gas Composition Inside Trays

The O_2/CO_2 concentrations in the trays were detected periodically every week by the OxyBaby gas analyzer (HTK, Hamburg, Germany) before opening each package throughout storage (Caner et al., 2023a).

pH Measurement

The pH of the fresh strawberries was determined regularly every week in 20 °C. After opening the trays, strawberries were divided into three groups and were placed in a blender, and the obtained juice was transferred into glass beaker to further measurements. Analyses were carried out by dipping a pH meter (Atagon PAL-1 Osaka, Japan) probe into the strawberry juice in the beaker (Caner et al., 2023a; Yüceer et al., 2016).

TSS

The total soluble solid (TSS) content value of the berry juice was measured using a refractometer (Pal-1, Atago Co., Tokyo, Japan) (Caner et al., 2023a).

Surface Color Measurement

The surface color was measured using a CR-400Chroma Meter (Minolta. Co., Japan) during storage. "L^*" and "a^*" values were obtained (Caner et al., 2025a).

TPA

Texture profile analysis (TPA) parameters were measured using the TA-XT-Plus Texture Analyzer (Stable Micro Systems Co., Surrey, England) using SMSP/10CYL. 5.0 mm/s, test speed 1.0 mm/s; drilling distance 4 mm and waiting time between two turns 5; trigger force is determined as 1.0 N. Parameters such as hardness, adhesiveness, gumminess, springiness, resilience, chewiness, and cohesiveness were measured/calculated automatically by the computer software (Caner et al., 2025b).

Total Anthocyanin Analysis

The extracted strawberry juice was filtered into the beaker using cheesecloth. Absorbance measurements on the prepared samples were done using a spectrophotometer (Jenway 7205, UK) at 400-nm and 600-nm wavelengths. It was evaluated that at that wavelength, the higher absorbance was given. The value of the highest absorbance was measured as 520 nm appropriate wavelength. The absorbance measurement was made at 520-nm (maximum wavelength) and 700-nm wavelengths to detect turbidity elements for pH 1.0 and pH 4.5. Three replicates were made for each sample. The total anthocyanin content was finally calculated according to Caner et al. (2025b) and expressed as mg/100 g on a fresh weight basis.

Total Phenolic Content

The 50-µL strawberry juice was taken from the thawed samples in a dark environment and made up to 1000 µL with distilled water, 5 mL of 0.2 N Folin-Ciocalteu's phenol reagent, and 4 mL of 7.5% Na_2CO_3 solution after vortexing for 2 h. It was calculated by reading the absorbance at 765 mm and creating a curve in terms of gallic acid. Three replicates were made for each sample. The total phenolic content was finally calculated according to Caner et al. (2025b) and expressed as mg/100 g on a fresh weight basis.

Fungal Decay Evaluation

Visual evaluation was done by counting the number of individual berry with mold symptoms (decay, lesions, or visible fungal growth) as decayed. The decay incidence was determined as the % of the infected fruit in trays based on Caner et al. (2025b) during storage.

Statistical Analysis

Statistical analysis was performed using the MIXED procedure of the SAS V9 (SAS Institute Inc., NC, USA) program. The effects of EW rates (30 ppm and 90 ppm), chitosan coating, storage period (1–5 weeks), and their interactions were evaluated using the Tukey test, taking into account the significance level of $p < 0.05$.

Results and Discussion

The Weight Loss

The quality of most fruits and vegetables declined, becoming unsellable as fresh produce after only minor moisture losses of 3–10% of the product weight. Weight loss (WL) and decay occurring during post-harvest storage in fresh strawberries are the most common physiological events. Water loss causes wilting, shrinkage, and browning; loss of fruit texture and taste; and accelerated aging.

It was noticed that the control had the highest weight loss (1.21%), and samples with chitosan coating showed much less WL (0.34%), EW, and coatings (0.36%) compared to the untreated and those with only electrolyzed water (0.79%−30 ppm, 0.70%−90 ppm) after 5 weeks of storage (Fig. 1).

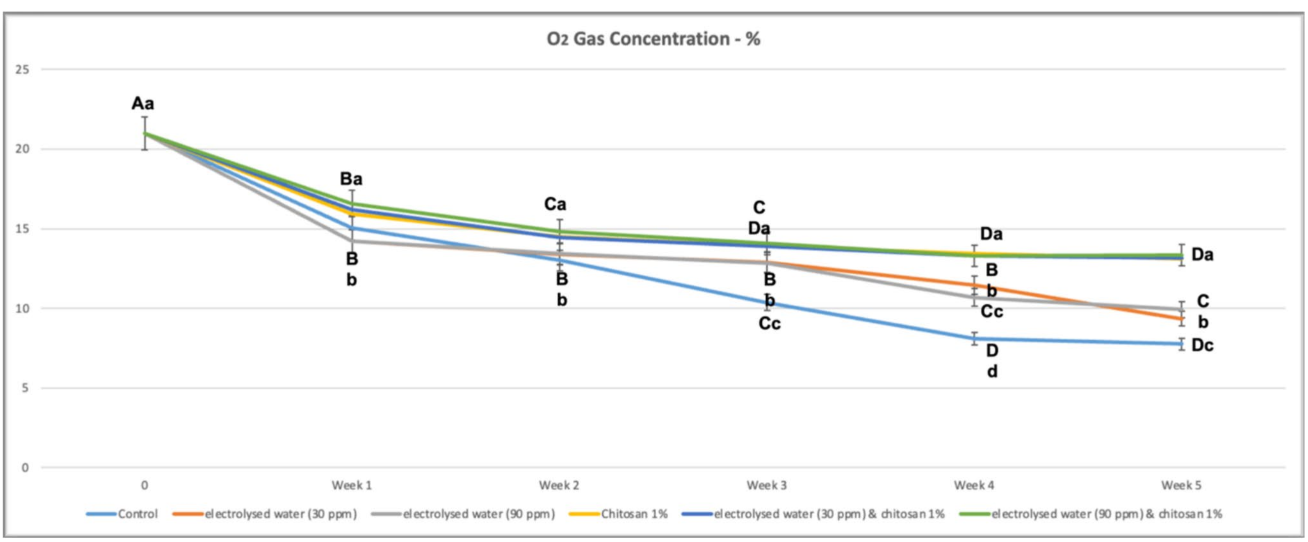

Fig. 1 Effect of electrolyzed water treatment and chitosan coatings on weight loss (%) of strawberries (5 weeks storage). Results were presented as means ± standard deviations of triplicate measurements ($n = 3$)

The less decrease in WL of the chitosan-coated berry was due to the efficiency of the chitosan coating layer on the berry acting as a semi-permeable barrier against gases to minimize evaporation of water, rate of respiration, and infection of microorganisms (Zhang et al., 2019). Coatings act as a modified atmosphere that retards the senescence of fresh berry more efficiently by controlling the internal metabolism (Zheng et al., 2024). Electrolyzed water-applied strawberry exhibited inhibited activity of enzyme, including in peroxidase and PPO, which was connected to an essential act in the softening process of respiration and production of ethylene (Sun et al., 2022). EW-treated longan fruits had consistently lowered the rate of respiration and the increment of longan pericarp cell membrane permeability and delayed the developments of berry disease as compared to the untreated fruit at the same storage period. The weight loss in fresh strawberries is related with the respiration rate and evaporation of water through the fruit surface; the rapid loss of water is the main factor related with the perishability of fruits, leading to shrinkage and deterioration (Zhang et al., 2019). Our results highlight that the storage period is a variable and correlated with weight loss. Postharvest AEW treatment could noticeably decline longan fruit respiration rate, pericarp browning, and pulp breakdown; keep adequate industrial acceptable fruit rate; and inhibit degradation of longan pericarp pigments and the appearance color change of longan fruit (Chen et al., 2020).

The results of this research were in parallel with that highlighted by Hayta and Aday (2015) who published that the low respiration rate of sweet cherries treated with EW (25, 50 and 100 mg/L) might be related with the inhibition of microbial growth.

EW and chitosan coatings could delay fruit metabolism to reduce WL and retain berry firmness. This weight moisture loss–related moisture decrease in the outer cell layers of the strawberry may be related with earlier publications in which the thickening and corrugation of the cell walls of parenchyma cells and epidermis are related with strawberry firmness (Caner et al., 2025b; Paniagua et al., 2013). EW alone affected definitely the decreasing weight loss. However, the chitosan coatings positively infected the decreasing WL through the storage; the preferable application was EW followed by chitosan biocoatings. The similar outcome has been highlighted with ClO_2 for cherry tomatoes and blueberries (Song et al., 2011) and strawberry (Caner et al., 2025b). The slightly acidic electrolyzed water (SAEW)-apple essence microencapsulation (AEM)-treated one showed a slightly reduced WL which correlated with the untreated one at 19.17% after 10 days. Contrarily, the chitosan–apple essence microencapsulation (CH–AEM) coating-treated one showed a more significant decline in WL at 16.10% after 10 days, presenting a considerable reduction of 4.22% compared to the untreated one. Furthermore, the SAEW.CH.AEM-treated one showed the most efficient preservation, with the lowest WL rate of 16.71% after 10 days, presenting a reduction of almost 3.61% compared to the untreated one. These outcomes offer that the chitosan biocoating is efficient in decreasing WL in fresh-cut apples during storage (Luo et al., 2024).

In this research, all the fresh berry trays would have still been marketable through the storage due to the 1.2% weight loss that was much lower than the 3–10% (Chiabrando et al., 2017).

Headspace Gases

During respiration, fresh fruit uses O_2 to carry out its metabolic activities, producing CO_2 and heat. In a closed system such as packaging, the concentration (O_2/CO_2) in the headspace changes over time using a micro-perforated film to create an equilibrium-modified atmosphere during storage (Fig. 2a). When the O_2 concentration in the pack reduced, respiration begins to slow down. The respiratory slowdown continues until O_2 reaches 2–5% for most products. Similarly, as CO_2 concentration increases above the atmospheric level, respiration rate, C_2H_2 production and susceptibility to C_2H_4, and suppression of microorganism activities result in inhibition of mold/bacteria growth (Mangaraj & Goswami, 2009; Caner et al., 2025b). It is well known that changes in CO_2/O_2 can cause changes in the respiratory pathways of the plant cells. Chitosan biocoating significantly suppressed the activity of succinic dehydrogenase (SDH) enzyme and increased the total activity of glucose-6-phosphate dehydrogenase (G-6-PDH) and 6-phosphate-gluconate-dehydrogenase (6-PGDH) in postharvest produce during storage periods. This highlighted that the chitosan biocoating lowered the respiratory pathway of TCA and increased HMP (Zhang et al., 2019).

It was determined that with the amount of O_2 in the headspace of packaging, the CO_2 content also increased and the equilibrium O_2 concentration stabilized within the range of 12–14%. It was observed that O_2 concentration decreased and that strawberry maintained their storage stability for a longer period of time (Fig. 2a).

All groups exhibited similar patterns, i.e., a constant and gradual decrease in the O_2 amount and also an increase in the CO_2 during the storage (Fig. 2a, b). From the general trend, it was observed that the control samples exhibited the highest rate of respiration during the storage. It has been observed that chitosan coatings are highly effective in reducing the respiratory rate and creating an equilibrium atmosphere in trays. When the carbon dioxide (CO_2) values obtained were evaluated, it was observed that the highest carbon dioxide (CO_2) value formation occurred in the control samples. It was observed that the least carbon dioxide (CO_2) formation was achieved in the application of 90 ppm

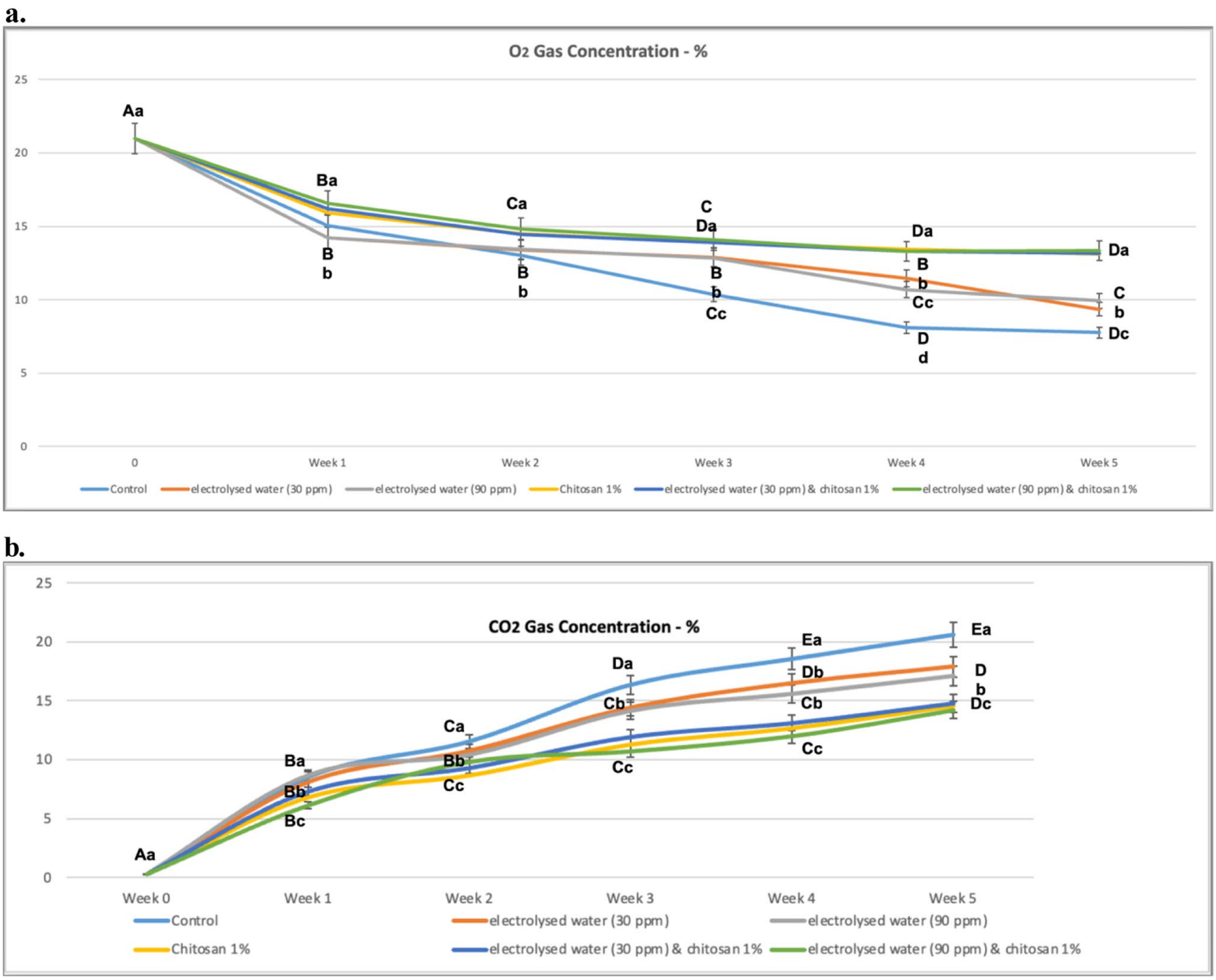

Fig. 2 **a** Effect of electrolyzed water treatment and chitosan coatings on O_2 gas concentration of strawberries (5 weeks storage). Results were presented as means ± standard deviations of triplicate measurements ($n = 3$). **b** Effect of electrolyzed water treatment and chitosan coatings on CO_2 gas concentration of strawberries (5 weeks storage). Results were presented as means ± standard deviations of triplicate measurements ($n = 3$)

EW and 1% chitosan coatings. These changes are highly related with the respiration rate of strawberry during storage. The package with chitosan coatings and EW applications decreased in the O_2 concentration and increased in CO_2 amounts through storage. Equilibrium-modified atmosphere for the strawberry was more successful when coating and EW were used together, and the rate of respiration begins to minimized which leads to enhanced storage stability (Krupa & Tomala, 2021).

Lowered O_2 and increased CO_2 concentrations decelerated the rate of respiration more than a single effect of each did and also caused lower activity of enzyme that results with less usage of substrates (organic acids and carbohydrate) and increased storability (Mahajan & Goswami, 2001). In this study, the O_2 concentration effectively decreased to 7% and CO_2 concentrations increased to almost 20% in the untreated one that induced rapid deterioration through the storage.

The coatings had similar O_2 (13%)/CO_2 (14%) concentrations that have an advantageous effect in slowing down the accumulation of CO_2 and providing an equilibrium state inside the trays (Fig. 2b). EW-30 ppm and 90 ppm applications also reduced the rate of respiration, which led to lower O_2 consumption and CO_2 production and that was more beneficial in enhancing the quality of the strawberry. It was alike published by Chen et al. (2020) that acidic EW (pH of 2.8, ACC of 48 mg/L for 5 min) delays the respiration rate of longan fruit. Zhang et al. (2023) also published that acidic EW application (pH = 6.0 and ACC = 80 mg/L) has a major effect on inhibiting the respiration rate of carambola fruit.

The study found that SAEW had a restricted ability to slow down the respiration rate of fresh-cut apples over extended storage; however, its combined impact with chitosan was less apparent. This could be related to the fact that SAEW adequately inhibits the metabolism of microbial respiration, slowing the respiration rate of fresh-cut apples until a specific point (Luo et al., 2024).

Rico et al. (2008) found that the O_2 use and CO_2 production decreased in the lettuce packaged with EW-60 ppm. Furthermore, the low respiration rate may be associated with the inhibition of microbial growth on mizuna baby leaves treated with EW-40, 70, 100 ppm (Tomás-Callejas et al., 2011). The 50 ppm and 100 ppm EW treatments decreased the rate of respiration and 50 ppm EW highlighted a significant effect in the decline in the respiratory rate among the other groups (Caner et al., 2025b).

The Embden-Meyerhof-Parnas (EMP)-tricarboxylic-acid-cycle (TCA) related to the main respiration and energy-generating pathway in fresh produce and performed an important function in regulating the senescence of postharvest fruit (Zhang et al., 2019). It is well known that the fresh strawberry respiratory pathways correlate with changes in the external environment; O_2/CO_2 atmosphere treatment of O_2 (13%)/CO_2 (14%) decreases the rate of the phosphopentose pathway and TCA in fresh strawberry. It was agreed upon that EW and chitosan biocoatings could reduce the process of respiration by changing ethylene biosynthesis and ethylene signaling pathways (Supapvanich & Kijka, 2021). Therefore, except for the mechanism of induced resistance as an exogenous elicitor, this research highlighted the decrease of respiration rate by chitosan coating and combination of EW with coating in fresh strawberry and the change of the respiratory pathway metabolism.

Total Soluble Solid

The primary reasons for the shortening of the storage time of fresh strawberries are the physiological processes and biochemical reactions that occur in the tissues and the growth of microorganisms on their surfaces. It is observed that the brix-total soluble solids (SSDs) decreased slightly during storage in all groups due to ongoing respiratory activities (Table 1). Metabolic activities that continue in this way cause complex substrates such as sugar, organic acid, and starch to be broken down and converted into energy (Samsudin, 2010). It was determined that with increasing storage time, the SSD value of the strawberry gradually decreased for all treatments (8.7 to 6.7–7.85° Brix) at the end of storage (Table 1). Statistical analysis exhibited that storage has a significant impact on SSD value ($p < 0.05$). It is observed that the value of SSD decreases through storage due to the use of sugar as a substrate in enzymatic reactions. However, as the storage period progresses, it can be seen that

Table 1 Effect of electrolyzed water treatment and chitosan coatings on total solid content (°Brix %) values of strawberries (5 weeks storage)

Treatments[a]	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5
Control	8.72±0.02Aa	8.37±0.09Ba	7.65±0.11Ca	7.30±0.1 Da	7.15±0.1Ea	6.73±0.1Fa
Electrolyzed water (30 ppm)	8.72±0.02Aa	8.50±0.11Bb	7.90±0.09Cb	7.85±0.1Db	7.45±0.07Eb	7.10±0.08Fb
Electrolyzed water (90 ppm)	8.72±0.02Aa	8.55±0.05Bb	7.85±0.07Cb	7.80±0.12Db	7.50±0.11Eb	7.23±0.01Fc
Chitosan 1%	8.72±0.02Aa	8.62±0.08Bc	8.20±0.11Cc	8.05±0.09Cc	7.70±0.12Ec	7.60±0.07Fd
Electrolyzed water (30 ppm) and chitosan 1%	8.72±0.02Aa	8.60±0.07Bc	8.35±0.012Ccd	8.15±0.05Cc	7.90±0.06Ed	7.62±0.09Fc
Electrolyzed water (90 ppm) and chitosan 1%	8.72±0.02Aa	8.60±0.1Bc	8.40±0.12Cd	8.25±0.08Cd	8.00±0.11Ed	7.85±0.08Fe

[a]Means in the same column with different lowercase letters (a–e) and means in the same row with different capital letters (A–F) are significantly different ($p < 0.05$)

the amount of soluble dry matter in the samples treated with EW and chitosan is higher compared to the untreated one. It is revealed that the strawberry applied with EW and also chitosan coatings have slower decrease in brix and higher brix values comparing to the untreated one. This could be because EW's chemical effects reduce the activity of enzymes involved in the metabolism of carbohydrates, maintaining a high concentration of soluble solutes. Early in the storage process, the rate at which insoluble polysaccharides convert to organic acids is higher than the rate at which mono- and disaccharides ferment. The lack of acidity brought on by age is another factor contributing to SSD decline (Fan et al., 2019).

Brix significantly reduced in all groups, and control groups had the lowest brix among all treated groups at the end of the storage. The control showed the highest decrease in °Brix (6.73), while the 90 ppm with chitosan coatings had the highest value (7.85) compared with the others at the end of storage. It was similarly published by Caner et al. (2025b) that (50 and 100 ppm) EW treatments delayed the reduction of Brix in fresh strawberry (Table 1). Increased respiration rate and sugar content are correlated with higher Brix decrease in the headspace of the untreated one, which is consistent with their higher CO_2 concentrations.

Different concentration (30 and 90 ppm) treatments have a statistically insignificant impact on Brix value, but chitosan coatings with EW is better compared with other treatments. It is related with the fact that coatings and EW reduced the level of CO_2 inside the package and slowed down carbohydrate metabolism (Kartal et al., 2012). The total soluble solids' values can be related with the weight loss and sugar content, as carbohydrates are the major substances that influence TSS values. The Brix results highlighted that chitosan coatings and EW clearly reduced the rates of respiration and Brix decrease by lowering physiological activity using the least sugar content during respiration, and EW and chitosan coatings ensure considerable Brix stability in strawberry and may be advantageous in the maintenance of storage stability during extended storage.

pH

The pH increased slightly due to usage of organic acid in the respiration process through storage. The outcomes from the research underline that the pH level increases during storage. As a result of the oxidation of the organic acid, CO_2, H_2O, and C_2H_4 are produced, increasing heat and decreasing acidity (González-Buesa & Salvador, 2022). Chitosan coatings create a modified atmosphere that prevents quick organic acid consumption by decelerating the rate of respiration.

It was observed that the pH values of the fruits increased through storage. The impact of all storage conditions and storage time on the pH values of fresh strawberries was found to be statistically significant ($p < 0.05$). It was observed that chitosan coating application made a statistically significant difference between storage ($p < 0.05$). However, the highest pH values throughout storage were determined in the control ones. As the ripeness of the fruit progresses, there is usually an increase in the pH (Table 2).

While the average pH value of fresh strawberry samples on the initial day was 3.36 in the control group, it reached 4.05 at the end of 5 weeks. In the samples with chitosan coating, it was observed that this change progressed much slower after the second week and was limited to 3.84 after 5 weeks (Table 2). When the pH values obtained were compared, the control group (4.03) showed the highest increase depending on the storage intervals. Higher CO_2 percentage in the package may result in faster rates of solubilization of CO_2 which would increase the amount of HCO_3^- (González-Buesa & Salvador, 2022). It was noted that the pH value was lower in the EW and chitosan coating groups (3.69) that keep O_2/CO_2 in equilibrium as a result of declining rates of respiratory when compared with the untreated and individual EW–treated groups due to the slower increase in pH that was observed. The deterioration of organic acids during storage is the cause of this rise. According to some reports, acetic and lactic acid bacteria, which generate acid from carbohydrates and alcohols, could be the reason for the rise in titratable acidity. On the other hand, the modified atmosphere created prevents the acceleration of organic acid consumption by slowing down the respiratory rate (Sweetman et al., 2014). Thus, the O_2/CO_2 in the trays showed a direct correlation with pH, and the amount of both changed simultaneously.

These findings are consistent with those of Caner et al. (2025b), who reported that the pH of strawberries increased and was dependent on the type of MAP used during storage.

Surface Color

The visual quality of the strawberry is one of the main parameters to purchase as customers prefer good-looking fresh products. The change in color is considered a sign of aging and reduces product marketability (Caner et al., 2025b). Changing the external color of the strawberry was correlated with decreasing lightness (L^*) and a^* (redness) values through the storage. Fruit color in fresh strawberries is associated with the accumulation of carotenoids and anthocyanins. Both pigment groups are more abundant in the peel, and anthocyanins are directly responsible for the fruit surface color.

There are three factors that contribute to the loss of fruit surface color during storage: rising respiration rate, browning processes, and the unstable anthocyanin pigment (red) being lost (Enaru et al., 2021). The AEW-treated longan fruits' L^* value rose for the first 2 days of storage before

Table 2 Effect of electrolyzed water treatment and chitosan coatings on pH values of strawberries (5 weeks storage)

Treatments[a]	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5
Control	3.36 ± 0.02Aa	3.37 ± 0.02Aa	3.57 ± 0.01Ba	3.64 ± 0.01Ca	3.76 ± 0.02 Da	4.03 ± 0.02Ea
Electrolyzed water (30 ppm)	3.36 ± 0.02Aa	3.36 ± 0.02Aa	3.49 ± 0.03Bb	3.58 ± 0.01Cb	3.63 ± 0.02Db	3.89 ± 0.03Eb
Electrolyzed water (90 ppm)	3.36 ± 0.02Aa	3.36 ± 0.02Aa	3.49 ± 0.02Bb	3.56 ± 0.02Cb	3.61 ± 0.03Db	3.85 ± 0.02Eb
Chitosan 1%	3.36 ± 0.02Aa	3.39 ± 0.02Aa	3.52 ± 0.02Bb	3.56 ± 0.01Cb	3.60 ± 0.02Db	3.75 ± 0.01Ec
Electrolyzed water (30 ppm) and chitosan 1%	3.36 ± 0.02Aa	3.38 ± 0.02Aa	3.51 ± 0.02Bb	3.57 ± 0.02Cb	3.58 ± 0.03Cb	3.72 ± 0.01Dc
Electrolyzed water (90 ppm) and chitosan 1%	3.36 ± 0.02Aa	3.38 ± 0.01Aa	3.49 ± 0.01Bb	3.56 ± 0.02Cb	3.57 ± 0.03Cb	3.69 ± 0.01Dd

[a]Means in the same column with different lowercase letters (a–d) and means in the same row with different capital letters (A–D) are significantly different ($p < 0.05$)

declining, but it was consistently greater than that of the untreated group (Chen et al., 2020).

At the conclusion of storage, there was no significant difference ($p > 0.05$) in color values between the EW, chitosan coatings, and EW-coating combination groups; nevertheless, the control group's color values were less bright, less red (a^*), and darker (lower L^*) (Fig. 3a, b).

When compared to the untreated ones, the L^* value decreased significantly in all treated cases. At 5 weeks, the EW-90 ppm had the greatest value (354) and the untreated had the lowest L^* value (31) (Fig. 3a). It is also highlighted that storage periods have a significant impact on (L^* value) color change. However, when it came to the brightness of the fruit's outer surface color (or L^* value), there was no significant difference ($p > 0.05$) between the treatments. When the a^* values were evaluated, it was revealed that intensities of the L^* and a^* color in fresh berries were related with when berries were treated at 30 and 90 ppm EW. A significant ($p < 0.05$) decrease happened in L^* and a^* values of the fresh berries through the 5 weeks, mainly after 2 weeks. Nevertheless, there was no statistically ($p < 0.05$) important variation among the groups (Fig. 3a, b).

This outcome agreed with that published by Hayta and Aday (2015) in which EW (25, 50, and 100 ppm)-treated cherries and strawberry EW (50 and 100 ppm) showed higher a^* values than the other treated ones and untreated one during long-term storage (Caner et al., 2025b).

EW application exhibited a significant role in preserving the brightness of the color of the strawberry surface and in decreasing the change of a bright appearance, highlighting that EW application could lessen the improvement of strawberry pericarp browning and hence maintain higher marketability appearance and acceptable rate of fresh berry through the storage.

Texture Profile Analysis

In the texture profile analysis (TPA) result exhibited that the hardness, gumminess, chewiness, internal stickiness, flexibility, and resilience decreased in the strawberry samples, while the external stickiness value increased (Caner et al., 2025b).

Hardness can be expressed as the highest force loaded to the fruit during the first compression. The hardness of the berry is significantly affected by the ripeness of the fruit. Softening is a progression programmed ripening mechanism in most fruits, offering different textures with a variety of fruits such as juiciness, crispness, and firmness (Chauhan et al., 2006). Postharvest softening is a key issue restricting the storage stability of fresh strawberry. Degradation of the cell wall and turgor pressure decrease in the cells due to water loss during storage are related to decreasing strawberry hardness.

Fig. 3 **a** Effect of electrolyzed water treatment and chitosan coatings on *L** color values of strawberries (5 weeks storage). Results were presented as means ± standard deviations of triplicate measurements ($n = 3$). **b** Effect of electrolyzed water treatment and chitosan coatings on *a** color values of strawberries (5 weeks storage)

During storage, hardness was reduced, and the minimum values were recorded at the end of the storage. Hardness consistently reduced as a function of storage weeks, from the initial day 1127 gf to 420–628 gf after 5 weeks of storage (Fig. 4). These values decreased the most to 420 g in control 1. At 5 weeks, the best values were obtained at 578–628 g with a decrease of 47–50% in the coated and also combination of the EW and coatings treatments; however, the control ones with a decrease of 62.7% had the highest percentage of reduction at initial values. It was determined that there was a significant difference between treatments and the control group after 5 weeks of storage ($p < 0.05$).

Previous research highlighted that pulp breakdown of fruits involved the action of cell wall–degrading enzymes

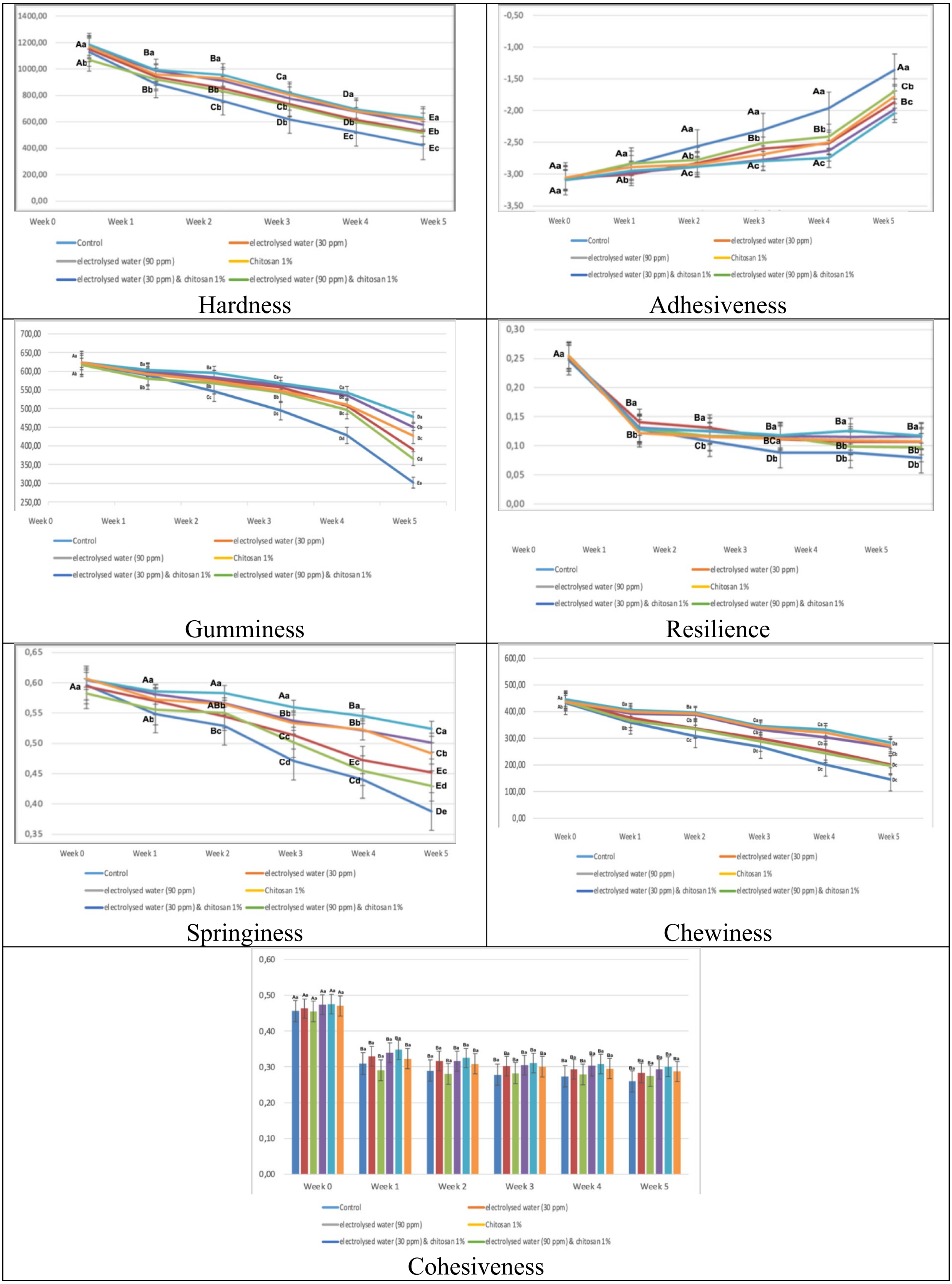

Fig. 4 Effect of electrolyzed water treatment and chitosan coatings on texture profile analysis values of strawberries (5 weeks storage)

(CWDEs) like polygalacturonase, β-galactosidase, xyloglucan endo-transglycosylase, pectinesterase, and cellulase, which led to cell wall disassembly (Chen et al., 2020). Applications of chitosan biocoatings (Caner et al., 2025b) or EW were able to decrease the degradation of cell wall components by inhibiting CWDE activities, and so maintained the cell wall integrity, and retarded pulp breakdown. These results underlined that the use of EW treatment to postpone the pulp breakdown of fresh berry might be due to similar reactions via reducing CWDE activities (Chen et al., 2020).

Coatings containing chitosan improved stiffness retention during storage. Preserving firmness helps keep strawberries from drying out by lowering physiological breakdown processes caused by EMAP (Caner et al., 2025b). Weakening the cell wall and increasing the cell separation by decreasing turgor in cells during storage results in economic loss (Brizzolara et al., 2020). With EMAP trays, decrease in CO_2 concentration and increase in O_2 concentration cause the postponement of the decrease of hardness.

At the 5th week, the value of combination of EW with chitosan-coated samples with hardness of 616–628 gf was quite similar to the 3rd week values of those untreated (618 gf). It is evident that chitosan coatings and EW preserved the turgor, adhesion, and strength of the strawberry cell walls while also reducing the fruit's respiration rates and producing a high degree of firmness (Li et al., 2022). This agreed with Caner et al. (2025b) who highlighted that the firmness was retained at its best at 100 ppm EW and 50 ppm compared to the initial values during storage. Zhang et al. (2023) published that the firmness of the carambola fruit reduced through storage, but the loss was delayed by SAEW application during storage. Combination of the chitosan coatings and EW can reduce the activity of cell wall decomposition enzyme, so as to preserve the cell wall, inhibit fruit softening, and improve the shelf life. The mechanical strength of cell wall structure was remarkably enhanced by applying chitosan coatings, consequently delaying the loss of firmness. Consequently, berry softening is slowed down, berry quality is enhanced, and berry storage stability is improved. Such efficacy in maintaining hardness (reducing softening) is related partly to reducing respiration rates by creating EMAP. Pectin and hemicellulose degradation of cell walls may be limited by variations in the headspace composition and, more importantly, the levels of CO_2 attained in trays, which may also have restricted the activities of polygalacturonase PG and pectin methylesterase (PME) (Vicente et al., 2005). In comparison to the untreated apple after 10 days, the combinations of the chitosan-AEM and SAEW–chitosan–AEM consistently maintained higher firmness values during the storage, with an increase in apple firmness loss of 30.93% and 30.45%, respectively. The similarity in firmness values between the SAEW–chitosan–AEM and chitosan–AEM demonstrated that although SAEW may not have a significant impact, chitosan plays a major role in maintaining apple firmness (Luo et al., 2024). Furthermore, the firmness had strong inverse correlation with weight loss, showing that the reduction of firmness was mainly related with the decrease in vapor pressure that resulted from the mass transfer of mainly water. In addition, the degradation of cell wall polysaccharides (cellulose, hemicelluloses, and pectins) also contributed to the fruit softening (Zhao et al., 2021). The adhesiveness values significantly increased from − 3.07 (initial weak) to − 1.36. (control) to − 2 (treated group) g sec at 5 weeks (Fig. 4). Compared with the untreated one, adhesiveness was preserved in the treatments especially in chitosan-coated groups. The control group exhibited the lowest adhesiveness value of − 1.36. It was amply demonstrated that during storage, adhesiveness increased steadily and significantly. Coatings and EW have been shown to delay the solubilization and depolymerization of strawberry cell walls, or pectin, during storage. The retardation of the adhesiveness in the coating and EW-treated strawberry can be also associated with the limitation of microbial activity by keeping O_2/CO_2 EMAP state and with reducing the activity of the enzyme.

Springiness decreased significantly (0.6 to 0.4–0.52), the lowest being especially in the control treatments (0.4) throughout the storage (Fig. 4). The springiness of the chitosan-coated and combination of EW with coatings was significantly maintained during storage (0.48–0.52) (Fig. 4). However, there were no significant differences between the coated and combination and coatings groups, but the 30 ppm (0.45) and 90 ppm (0.43) group exhibited a lower value than the other treated group but higher than the control ones at 5 weeks of storage (Fig. 4).

Cohesiveness shows that chitosan coatings and combination of EW and coatings have a significant impact (Fig. 4). The storage process consistently resulted in a loss in cohesion (Fig. 4) because the cell wall and middle lamella pectin were breaking down (Chauhan et al., 2006). The control ones had the highest decreases (from 0.46 to 0.26). There were insignificant changes in terms of cohesiveness among treated ones.

Gumminess declined through storage from 621 to 301 (control) and 450–477 in coated and also 370–390 EW-treated ones (Fig. 4). This decrease is more pronounced in the control one, decreasing from 621 to 301 due to the water leak (softening) leading to a softer and more elastic fruit structure. The starch hydrolysis caused the lower gumminess (Caner et al., 2008).

The decrease in chewiness (Caner et al., 2008; Chauhan et al., 2006) is more pronounced when compared to the cohesiveness. The chewiness reduced due to the reduced hardness. It was also showed that coatings act as barrier and lower decreasing rate. Coatings limit the cellulosic and pectic enzyme activity by maintaining O_2/CO_2 as stable.

Chewiness reduced from 432 to 145 (untreated) and from 273 to 283 (EW with coatings treated) and also from 197 to 201 EW at the end of storage (Fig. 4) and became softer during the postharvest storage.

The TPA results and the variations in pH and Brix showed a strong correlation. It is probable that the EW and chitosan coatings improved the TPA of fresh strawberries by focusing on changes in the cell-wall structure, particularly hardness.

Total Monomeric Anthocyanin

Anthocyanins, ellagitannins, and proanthocyanins are the main polyphenols found in fresh strawberries (Sandhu et al., 2018). Given that anthocyanins are known to be unstable, there has been significant loss and observed alterations to their molecular structures (Kadivec et al., 2013).

The first 21 days of storage had no discernible impact on the levels of anthocyanins ($p > 0.05$) (Table 3). However, following week 3, there is a noticeable decline. The treated sample had much higher quantities of anthocyanin (122–30 ppm EW with coatings and 124–90 ppm EW with coatings) than the untreated one (148 to 101 ppm, or around 31% loss). The use of chitosan coatings in conjunction with 30 ppm and 90 ppm EW can considerably be correlated with the delay in the breakdown of anthocyanin (17–18%) during storage, as demonstrated by the results of 5 weeks of storage (Table 3).

Our results are consistent with those of Chen et al. (2020), who conducted research on longan fruit.

The above results indicated that EW treatments can impede the breakdown of bioactive substances and pigments, such as anthocyanins, carotenoids, flavonoids, and chlorophyll and better maintain the appearance of the color of berry. At the conclusion of storage, it was seen that the combined effects of chitosan and EW produced more successful outcomes than the other groups; however, no statistically significant difference was observed between the treatment groups ($p < 0.05$).

Total Phenolics

Phenolic compound effects on odor and taste formation promote health benefits by reducing the risk of metabolic syndrome. There was a significant decrease in storage after 14 days. It can be seen that the highest decrease was in the control one, from 1610 ppm gallic acid to 810 ppm (a decrease of 49.67%). These values show that the treatments maintained stability in the total phenol amount compared to the untreated one. The highest amount of total phenol (1086 ppm) was measured in the samples with the combined treatment of EW with 1% chitosan ($p < 0.05$) at 35 days (Table 4). The combined treatment was positively correlated with phenol content. The phenolic reduction may be a result of the reduction in sugar amount, which suppresses the metabolic pathway of their synthesis (Formiga et al., 2019). During storage, the aging process, dissolution of cell wall pectic components, and microbial invasion caused degradation of subcellular components, oxygen interference, and disruption of cell membrane integrity. This increases the activity of polyphenol oxidase (PPO), which is responsible for phenol oxidation. Previous studies show that chitosan application reduces PPO activity and increases phytochemical component content in strawberries. However, the decrease in phenolic components during long-term storage is explained by cell wall disintegration and exposure of phenolics to enzymatic oxidation (Salazar-Orbea et al., 2023).

Visual Evaluation

The two most damaging gray molds that cause substantial degradation in strawberries during handling are *Rhizopus* sp. and *Botrytis cinerea* (Caner et al., 2025b). When the number of moldy and rotten strawberries in the package is monitored during storage, it is seen that the samples with chitosan coating and EW application give more successful results compared to the untreated one (Fig. 5; Table 5). It is noticed that there is a significant increment in the rate

Table 3 Effect of electrolyzed water treatment and chitosan coatings on total anthocyanin content (mg/100 g on a fresh weight basis) of strawberries (5 weeks storage)

Treatments[a]	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5
Control	148.29 ± 2.1Aa	149.08 ± 2.2Aa	149.37 ± 1.7Aa	129.79 ± 1.4Ba	115.89 ± 1.8Ca	101.95 ± 1.7 Da
Electrolyzed water (30 ppm)	152.67 ± 1.2Aa	153.13 ± 2.5Aab	149.75 ± 1.3Ba	145.07 ± 2.1Cb	136.10 ± 2.7Db	111.84 ± 2.2Eb
Electrolyzed water (90 ppm)	152.50 ± 2.1Aa	155.55 ± 2.9Ab	159.27 ± 2.0Bb	149.50 ± 3.1Cc	138.23 ± 2.4Db	116.47 ± 2.9Ec
Chitosan 1%	151.83 ± 1.7Aa	150.25 ± 2.3Aa	151.42 ± 2.4Ac	136.54 ± 2.1Bd	129.33 ± 2.6Cc	113.84 ± 3.2Ec
Electrolyzed water (30 ppm) and chitosan 1%	149.58 ± 2.4Aa	154.13 ± 2.1Bb	153.38 ± 2.3Bc	142.83 ± 2.8Cb	135.22 ± 2.2Db	122.15 ± 2.4Ed
Electrolyzed water (90 ppm) and chitosan 1%	149.96 ± 2.0Aa	155.34 ± 2.3Bb	153.00 ± 2.6Bc	145.91 ± 2.8Cb	138.81 ± 3.1Db	124.28 ± 3.5Ed

[a]Means in the same column with different lowercase letters (a–d) and means in the same row with different capital letters (A–E) are significantly different ($p < 0.05$)

Table 4 Effect of electrolyzed water treatment and chitosan coatings on total phenol content (ppm gallic acid, mg/100 g on a fresh weight basis) of strawberries (5 weeks storage)

Treatments[a]	Week 0	Week 1	Week 2	Week 3	Week 4	Week 5
Control	1609 ± 66Aa	1599 ± 45Aa	1402 ± 37Ba	1321.1 ± 34Ca	935 ± 24 Da	816 ± 21Ea
Electrolyzed water (30 ppm)	1653 ± 69Aa	1659 ± 50Ab	1471 ± 32Bb	1422.8 ± 40Cb	983 ± 20Db	911 ± 23Eb
Electrolyzed water (90 ppm)	1646 ± 57Aa	1612 ± 47Aab	1571 ± 52Bc	1512.2 ± 49Bc	1013 ± 47Cb	882 ± 32 Da
Chitosan 1%	1627 ± 56Aa	1657 ± 54Ab	1546 ± 46Bc	1453.9 ± 57Cb	1227 ± 53Dc	1032 ± 37Ec
Electrolyzed water (30 ppm) and chitosan 1%	1628 ± 56Aa	1658 ± 57Ab	1595 ± 53Bcd	1425 ± 62Cb	1237 ± 58Dc	1049 ± 45Ec
Electrolyzed water (90 ppm) and chitosan 1%	1619 ± 51Aa	1646 ± 59Ab	1613 ± 54Ad	1440 ± 52Bb	1240 ± 52Cc	1086 ± 39Dc

[a]Means in the same column with different lowercase letters (a–c) and means in the same row with different capital letters (A–C) are significantly different ($p < 0.05$)

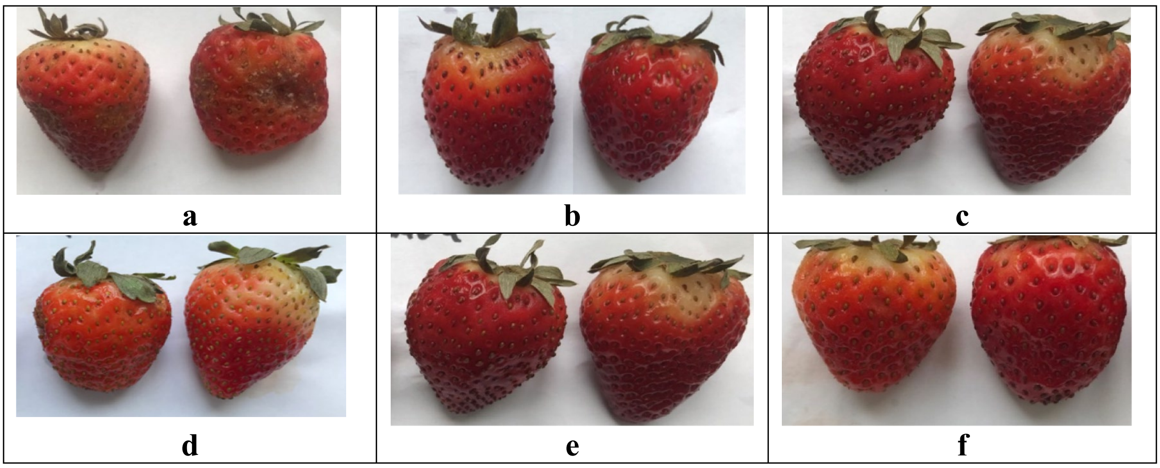

Fig. 5 Effect of electrolyzed water (EW) treatment and chitosan coatings on visual evaluation of strawberries at the end of the storage period (5th week): **a** control group, **b** chitosan 1% coating, **c** 30 ppm EW, **d** 90 ppm EW, **e** 30 ppm EW + chitosan 1% coating, **f** 90 ppm EW + chitosan 1% coating

Table 5 Effect of electrolyzed water treatment and chitosan coatings on rotten/moldy percentage (%) of strawberries in package (5 weeks storage)

Treatments[a]	Week 1	Week 2	Week 3	Week 4	Week 5
Control	25.00/33.33	33.33/50.00	66.67/58.33	66.67/75.00	16.67/25.00
Electrolyzed water (30 ppm)	16.67/25.00	16.67/50.00	58.33/41.67	58.33/33.33	0.00/8.33
Electrolyzed water (90 ppm)	16.67/16.67	16.67/33.33	50.00/41.67	50.00/25.00	0.00/16.67
Chitosan 1%	0.00/16.67	0.00/33.33	16.67/16.67	41.67/8.33	0.00/8.33
Electrolyzed water (30 ppm) and chitosan 1%	0.00/16.67	0.00/16.67	16.67/16.67	33.33/8.33	0.00/8.33
Electrolyzed water (90 ppm) and chitosan 1%	0.00/0.00	0.00/0.00	16.67/16.67	25.00/8.33	0.00/0.00

of fungal decays through storage. The highest fungal decay rate was seen in the control samples (67%), while combination of coatings and 90 ppm EW was at the lowest level (25%) at the end of storage (Table 5). It was evaluated that no fungal decay was observed in all coated groups on the 4th week. The fungal decay started after the first week in the control group and after the second week in the EW-treated samples. When the fungal decay rate is evaluated, the clear effectiveness of the chitosan application was seen, and the individual 30 ppm (58%) and 90 ppm (50%) EW application had limited effects on the decay rates (Table 5). Using chitosan coatings with EW application has a high potential for preventing fungal decay on berries. The similar findings were reported by Bessi et al. (2014), who showed that using EW considerably reduced the amount of mold and yeast present. Fresh produce treated with SAEW, an environmentally friendly disinfectant, has a very high success rate in reducing the amount of mold, bacteria, and viruses (Issa-Zacharia & Sagar, 2024).

Conclusion

Experimental results highlighted that compared to the control one, EW and coating application alone significantly enhanced the storage stability of the berry product. The concept of the synergetic decontamination process is a suitable, low-cost, and simple-to-use approach for disinfecting fresh berries. It also boosts the synergistic effect of chitosan coating and EW which have a positive effect together on slowing down the softening of strawberries during storage and on the inhibition of cell wall enzymes that affect the preservation of fruit firmness. In this case, the most efficient application is that the synergistic treatment of 1% chitosan and 30 or 90 ppm EW exhibited the best performance as an alternative technology to enhance the storage stability of strawberry while preserving the phenolic and anthocyanins during storage. In our study, it was observed that the color characteristics of strawberry fruit (L^* and a^*) were preserved with the deterioration of the delaying effect of EW, while chitosan coatings caused a darkening in color values.

At the end of this study, it was found that the storage stability was 1–2 weeks longer with the synergistic effect of EW and chitosan compared to the untreated one. Therefore, the exceptional synergistic efficacy attained by using chitosan coatings and EW together to maintain fresh berries results in an appealing, safe, and sustainable replacement for artificial preservatives in the fresh fruit industry. Longer transportation distribution in foreign markets and the possibility for exporters to send fresh fruits by sea freight at a significantly lower cost compared to air freight would be made possible by increased storage stability of 1–2 weeks. As a result, it can be utilized to enhance the safety and quality of fresh produce.

Despite improvements, mechanisms and optimal treatment techniques of combined applications need evaluation.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Ethical Statement Ethics approval was not required for this research. This study does not involve any human or animal testing.

Conflict of Interest The authors declare no competing interests.

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