RESEARCH ARTICLE

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Effects of postharvest edible coating applications on storage life and quality of some apple cultivars

Tuba Dilmaçünal[1] • **Emine Yiğit**[2]

[1] Department of Horticulture, Faculty of Agriculture, Isparta University of Applied Sciences, Isparta, Türkiye
[2] Ministry of Health Isparta City Hospital, Isparta, Türkiye

Abstract
In this study, the effects of postharvest calcium chloride dihydrate ($CaCl_2.2H_2O$), rosehip essential oil (REO) (cold pressed), and $CaCl_2.2H_2O$+REO combination edible coating applications on some fruit quality parameters and storage life of 'Starkrimson Delicious' ('S. Delicious'), 'Golden Delicious' ('G. Delicious') and 'Granny Smith' ('G. Smith') apple cultivars were investigated. For this purpose, the fruit was divided into four groups after harvest: 1st group: Fruit was dipped in distilled water (control), 2nd group: Fruit was dipped in 1.5% $CaCl_2.2H_2O$, 3rd group: Fruit was dipped in 2% REO, 4th group: Fruit was dipped in 1.5% $CaCl_2.2H_2O$+REO (%2) to form an edible coating on fruit. Before and during storage at periodical intervals weight loss, fruit color, fruit flesh color, fruit flesh firmness, soluble solids content, titratable acidity, pH, respiration rate, ethylene production, sensory evaluations (overall quality, taste and aroma, odor, decay) superficial scald, and superficial scald severity analyzes were performed. In the 'S. Delicious', the lowest weight loss was in $CaCl_2.2H_2O$+REO during and at the end of storage, REO had the lowest in the 'G. Delicious'. 'G. Smith' had lower weight loss in $CaCl_2.2H_2O$ and the control group than the others. The REO preserved the fruit flesh firmness better than others with the least loss. REO was the most effective treatment in suppressing ethylene production in all cultivars, followed by $CaCl_2.2H_2O$+REO. In 'S. Delicious' and 'G. Smith', fruit color and vividness of fruit color were best preserved by REO. As a result, postharvest edible coating applications of $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO in 'S. Delicious', 'G. Delicious' and 'G. Smith' had positive contributions in maintaining fruit quality attributes during storage.
Keywords: Apple, Calcium chloride dihydrate, Cold storage, Ethylene production, Rosehip essential oil

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Corresponding Author: Tuba Dilmaçünal
E-mail: tubadilmacunal@isparta.edu.tr

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INTRODUCTION

Apple is one of the world's most traded fruit, and consumer demand is changing rapidly (Bayav and Armağan, 200; Bayav, 2023) Apple is an important fruit type that has been cultivated in Türkiye for many years, ranks first among other temperate climate fruit in terms of cultivated area and production (Küden et al., 1997; Bayav and Karlı, 2020; 2021), and contributes to employment in marketing, packaging, processing and storage stages (Burak and Ergun, 2001) World apple production reached 93,144,358 tons. China ranks first in the world with a production of 45,983,400 tons, followed by the Türkiye (4,493,264 tons) and the USA (4,467,206 tons) (FAO, 2023). Türkiye increased its apple production by 55.53% in the last ten years (2012-2021), from 2,888,895 to 4,493,264 tons. Apple production ranks first when pome and stone fruit production in Türkiye is evaluated (Güner, 2019; Bayav et al., 2023). Isparta accounts for 20.4% of Türkiye's total apple production, with investments in processing, storage and

R&D infrastructure as well as production (TEPGE, 2019).

Apples are rich in bioactive compounds such as antioxidants, organic acids, phenolic substances and vitamins (Kuşçu and Bulantekin, 2016; Ozturk et al., 2022). Many cultivars are used in apple cultivation in the world, and 'Starking Delicious' and 'Golden Delicious' cultivars are among the widely cultivated cultivars in Türkiye (Mordoğan and Ergun, 2002). Among the apple cultivars cultivated in Türkiye, 'S. Delicious', 'G. Delicious', and 'G. Smith' apple cultivars occupy an important place in 4,817,500 tons (TurkStat, 2023). It is reported that 25-40% of fresh produce in Türkiye is lost after harvest for various reasons (Sayılı et al., 2006). Approximately 40% of the apples produced in Türkiye are consumed fresh, and late harvested apple cultivars such as 'Granny Smith', 'Braeburn', 'Pink Lady', 'Golden Delicious' group, 'Red Delicious' group and 'Fuji' group are among the apple cultivars that can be stored for a long time. It is reported that long-term storage is only possible in cold storages where important environmental factors affecting the storage period such as temperature, relative humidity, atmospheric composition and ethylene removal in the environment can be well controlled. However, in our country, due to the insufficient capacity of cold storage where the ambient factors can be fully controlled and high storage costs, a significant portion of the cultivars suitable for long-term storage are stored in uncontrolled conditions, which are called ordinary cold storages and do not have the possibility of mechanical cooling (Üstün, 2018).

The high fruit losses that occur during postharvest storage and the introduction of restrictive measures to control methods with plant growth regulators applications in order to reduce these losses have recently led researchers to natural applications. The fact that the toxic effect of the chemical substances used does not completely disappear in short-term stored products causes natural applications to be preferred as protection measures used to delay postharvest losses (Öz and Süfer, 2012). However, using safe practices to preserve fruit quality is an important activity to help prevent climate change (Kahramanoğlu, 2019). Recently, there has been a growing interest in using of natural compounds to maintain fruit quality and extend shelf life (Dursun, 2019). Therefore, alternative strategies are being developed to reduce losses due to postharvest spoilage that are perceived as safe by the consumer and pose no risk to human health and the environment (Wilson et al., 1997). In recent years, consumers have also become increasingly interested in consuming natural products (Pinheiro et al., 2012) and tend to buy fruits and vegetables free from diseases and defects and not treated with pesticides. However, importing countries also enforce strict import regulations on maximum residue limits on consumed portions of fruits and vegetables (Njombolwana et al., 2013). In recent years, essential oil treatments and calcium salts have been developed as alternatives to chemical methods to maintain the quality of fruits and vegetables, among which calcium chloride is the most widely used and successful. Essential oils, which have natural ingredients and are obtained from various plants, have recently been preferred against the disadvantages of chemicals after harvest, especially due to their antibacterial and antimicrobial properties. It has been reported that essential oil application is considered a safe practice for postharvest quality and decay control in fresh produce (Sivakumar and Bautista-Banos, 2014). Studies using postharvest calcium applications to extend the postharvest shelf life of fruits are also among the alternative practices (Poovaiah et al., 2003; Ranjbar et al., 2018; Gemeda, 2021). Depending on the salt type and calcium concentration, postharvest calcium immersion can significantly increase calcium content without causing fruit damage (Conway and Sam's, 2001; Hussain et al., 2012).

According to our research, no study investigated the effects of postharvest edible coating applications of rosehip essential oil (cold pressed) or calcium chloride dihydrate ($CaCl_2.2H_2O$) in combination with rosehip essential oil on the storage life and fruit quality of horticultural products. This study was conducted to investigate the effects of postharvest edible coating applications of $CaCl_2.2H_2O$, rosehip essential oil, and a combination of $CaCl_2.2H_2O$+rosehip essential oil treatments on the storage life and fruit quality of 'Golden Delicious', 'Starkrimson Delicious' and 'Granny Smith' apple cultivars throughout the the cold storage period of 6 months.

MATERIALS AND METHODS

The study was carried out at Isparta University of Applied Sciences, Faculty of Agriculture, Department of Horticulture Laboratories, Eğirdir Fruit Research Institute Postharvest Physiology Laboratory and Yuvalı Village Cold Storage in 2021. The study used apple fruit from three different cultivars: 'Starkrimson Delicious' ('S. Delicious'), 'Golden Delicious' ('G. Delicious'), and 'Granny Smith' ('G. Smith'). These cultivars were grafted onto a 15-year-old MM 106 rootstock and grown under conventional farming conditions at an altitude of 1276 meters in the Asaraltı locality of Yuvalı village, located in the Eğirdir district of Isparta province. The latitude of the orchard is 37.71, longitude 30.94, Asaraltı locality, island 188, plot 26 (Anonymous, 2023). In 2021, the average temperature was 12.3 °C and the average rainfall was 568.4 mm (Anonymous, 2022).

Healthy fruit was selected from the harvested fruit before the application by removing those damaged by any disease or pest, mechanically damaged and those with broken stems. Fruit was washed with tap water to remove dust and dirt. The washed fruit was kept in a cool, shady place for an hour to drain and dry (Shehata et al., 2020). The fruit of each apple cultivar were divided into four groups; Group 1: Control group and the fruit was immersed in distilled water for 5 minutes; Group 2: The fruit was treated with $CaCl_2.2H_2O$ (Tekkim Extra pure, Food quality) at a dose of 1.5% (Saftner and Conway, 1998; Chardonnet et al., 2003; Trentham et al., 2008; Hussain et al., 2012; Gago et al., 2016) for 5 minutes; Group 3: Rosehip essential oil (REO) coating was prepared by dissolving REO (Botalife, cold-pressed 100% pure Manolya Natural Aromatic Products Food Industry and Trade Co.Ltd.) in 0.5% Tween 80 and immersing it for 5 minutes in 2% final solution concentration obtained by adding distilled water (Paladines et al., 2014; Martínez-Romero et al., 2017; Martínez-Romero et al., 2019); Group 4: $CaCl_2.2H_2O$+REO combined application, the fruit was immersed in the $CaCl_2.2H_2O$ solution prepared as above at a dose of 1.5% for 5 minutes, (Saftner and Conway, 1998; Chardonnet et al., 2003; Trentham et al., 2008; Hussain et al., 2012; Gago et al., 2016), after the dipping treatment the excess solution was drained and then fruit was immersed in the REO solution prepared at a dose of 2% as described above for 5 minutes, (Paladines et al., 2014; Martínez-Romero et al., 2017; Martínez-Romero et al., 2019).

In the experiment, the treatments were performed in each apple cultivar in three replicates with 15 fruit in each replicate. The fruit was not subjected to pre-cooling. After the treatments, the excess solution of the fruit was drained in a cool and shady place (Shehata et al., 2020) and placed in plastic perforated 20 kg capacity crates separately for each cultivar and treatment. Apples were placed in the normal atmosphere (NA) commercial cold storage at 0 °C temperature and 90-95% relative humidity.

Weight loss

The fruit was labelled, weighed, and placed in storage for weight loss analyzis. The analyses described below were performed as beginning analyses prior to cold storage and periodically throughout the storage period on fruit samples removed from storage conditions. Weight loss (WL) was calculated by weighing the same fruit samples labelled and prepared before storage according to the equation presented below:

WL: (A1-A2/A1)x100 (A1: Initial weight, A2: Period weight) and given as %.

Fruit flesh firmness

Fruit flesh firmness (FFF) measured by removing the fruit peel with the help of Fruit Peeler-Italy in equal thickness and measured with the 11.1 mm probe of a digital penetrometer (Labor Teknik) and given in Newton (N).

Soluble solids content

Soluble solids content (SSC) was measured with a digital refractometer (Atago Pocket PAL-1 Japan) in blended and filtered juice and given in Brix° (Cemeroğlu, 1992).

Titratable acidity and pH

Titratable acidity (TA) was measured using a Hanna instruments HI221 model digital pH meter with a probe immersed in 10 ml of juice and titrated with 0.1 N NaOH using a Titrette model digital burette and titrated according to the formula A = S x N x F x E x 100/C (A: the amount of acid (mg malic acid/100mL), S: the amount of sodium hydroxide used (mL), N: normality of sodium hydroxide used, F: factor of sodium hydroxide used, C: the amount of sample taken (mL), E: equivalent value of the respective acid (malic acid)) (Karaçalı, 2002). pH was measured using a Hanna instruments HI221 model digital pH meter with a probe immersed in 10 mL of fruit juice.

Fruit color and fruit flesh color

For fruit color analyses, the fruit was labelled, color measured (Minolta CR-300 Model Japan) and placed in storage. Fruit color analyzes were performed on the same apple samples during storage. The analyses were performed as beginning analyses prior to storage and throughout storage on fruit samples removed from storage conditions periodically. Fruit flesh color analyzes were performed on the fruit samples at harvest date and during the cold storage removed from cold storage at monthly intervals.

Fruit color (FC) and fruit flesh color (FFC) were read according to CIE L^*, a^*, b^* values and evaluated as L^*, a^*, b^*, hue angle (h°=arctanb/a) and chroma ($C^*=(a^2+b^2)^{1/2}$).

Respiration rate and ethylene production

Respiration rate and ethylene production were measured simultaneously in a single gas sample from each jar. Measurements were made in S/SL inlet split mode with a gas sampling valve using a fused silica capillary column (GS-GASPRO, 30 m x 0.32 mm I.D.) in 1 a mL gas sample. Agilent brand GC-7890A model gas chromatography with a thermal conductivity detector (TCD) for respiration rate measurement, a flame ionization detector (FID) for ethylene production, and loaded into a computer to which it is connected. It was made using the Chemstation REV. B. 04.03 (16) package program. The carrier gas flow is 1.7 mL/min in constant flow mode. The temperatures of the furnace, TCD and FID detectors are 40 (isothermal), 250°C and 250°C, respectively. Gas flows for high purity hydrogen (H_2) and dry air used as carrier gas in FID are 30 and 300 mL/min, respectively. High purity helium (He) (makeup) and reference flow rates used as carrier gas in TCD are 7.0 and 20 mL/min, respectively. 0.5 kg of fruit was placed in 2 L jars and kept at 20^0C for 24 hours. Then, 10 mL of air was taken from the jars and reading was done in gas chromatography. The readings were evaluated according to Anonymous (2020) for respiration rate and according to Dixon and Hewett (2001) for ethylene production. Ethylene production is given in µL.C_2H_4/kg.h, and respiration rate in mL.CO_2/kg.h.

Sensory evaluations

In sensory evaluations, overall quality was evaluated on a scale of 1-9 (1≤4: unmarketable, 5: marketable, 6-8: good, 9: very good) (Dilmaçünal, 2009), the odor was evaluated on a scale of 0-5 (0: none, 1: very little, 2: little, 3: medium, 4: much, 5: very much) (Peña et al., 2013), taste and aroma was evaluated on a scale of 1-5 (1:very bad, 2: bad, 3: medium, 4: good, 5: very good) (Dilmaçünal, 2009), decay as % of fruit with rot in each analysis period (Yılmaz, 2019; Şener et al., 2022).

Superficial scald and superficial scald severity

Superficial scald (SS) as % of fruit with SS in each analysis period, and superficial scald severity (SSS) according to Mditshwa et al. (2018) (0: no superficial scald, 1: 1-25% very slight, 2: 26-50% slight, 3: 51-75% moderate, 4: 76-100% severe).

Statistical evaluation

In the study, the data obtained in terms of soluble solids content, pH, titratable acidity, fruit flesh firmness, and respiration rate were analyzed by using the variance analysis technique in factorial. In the experiment, there are three levels of variety factor, four levels of treatment factor and seven levels of month factor. The number of observations in subgroups was three. Tukey test, one of the multiple comparison methods, was used to determine the differences between factor level means.

It was determined that the data obtained in terms of ethylene production amount characteristic did not meet the prerequisites of parametric tests such as normality and homogeneity of variances as a result of Anderson Darling (Normality) and Levene (Homogeneity) Test respectively. Therefore, the Kruskal-Wallis test was used to determine whether the differences between the level medians of the factors were statistically significant. Dunn-Bonferroni test, one of the nonparametric multiple comparison methods, was used to determine the differences between the medians. Repeated measures analysis of variance technique in factorial order was applied to the data obtained in terms of fruit and flesh color (L^*, a^*, b^*) and weight loss characteristics. In the study, there were three levels of variety factor, four levels of treatment factor and six levels of time factor. Initial values of the time factor were included in the analysis as covariates. Repeated measurements were carried out at the levels of the time factor. Tukey test, one of the multiple comparison methods, was used to determine the differences between factor level means. Since the data obtained in terms of overall quality, taste- aroma, odor and decay characteristics did not meet the prerequisites for parametric tests, the differences between the level medians of any of the factors were compared separately in each combination of the remaining two. Statistical significance was determined by the Kruskal-Wallis test.

RESULTS AND DISCUSSION

Weight loss (WL)

In general, fruit weight loss is normally attributed to fruit senescence or water loss and is also used as a quality index for the postharvest life of fruit (Sati and Qubbaj, 2021). Through transpiration, WL is one of the major causes of quality deterioration in fresh horticultural crops after harvest. It causes not only direct quantitative losses, but also losses in appearance, textural quality (loss of softness, crispness and juiciness) and nutritional quality. If the WL is more than 10%, the fruit surface becomes prone to quality defects such as wilting and shriveling and the product becomes unmarketable (Hussain et al., 2012). In general, the WL was higher in the control group compared to the treated fruit during storage. According to the storage period, the highest (4.13%) WL was obtained in the 'S. Delicious' in the 6^{th} month. The WL increased in all treatments with the extension of the storage period. In 'S. Delicious' the lowest WL (2.59%) obtained from $CaCl_2.2H_2O$+REO at the end of the storage (Table 1).

Chardonnet et al. (2003) reported that $CaCl_2$ infiltration provides an increase in both total and cell wall-bound Ca in apple tissue during storage and reaches its maximum with $CaCl_2$ application in fruit stored for 4 or 6 months, thus protecting the cell wall. In 'G. Delicious' the lowest WL (0.80%) was in REO at the end of the storage. In 'G. Smith' $CaCl_2.2H_2O$ resulted in lower fruit weight loss than other applications during storage (Table 1), and was recorded as the most successful treatment in limiting weight loss in this cultivar. It is concluded that the reason for the obtained results could be related to the application of REO, which creates a modified atmosphere around the apple fruit as well as $CaCl_2.2H_2O$ protecting the cell integrity of the fruit. Although it varies depending on the cultivar, weight losses of more than 5% may cause noticeable wrinkling in apples during marketing. The 'G. Smith' can be counted among the cultivars in which the least wrinkling was observed due to its peel structure. Previous studies have also reported that essential oil and Ca applications limit weight loss in fruit during storage. This effect is known to be successful in fruit by directly preserving both the physiological metabolism associated with ripening and the tissue firmness of the fruit (Shirzadeh et al., 2011; Paladines et al., 2014; Gago et al., 2016; Martínez-Romero et al., 2017; El-Dengawy et al., 2018; AL-Saikhan, 2018; Mahmoud et al., 2019; Martínez-Romero et al., 2019; Gemeda, 2021; Mazumder et al., 2021; Sati and Qubbaj, 2021; Singh et al., 2022). Saftner and Conway (1998) investigated the effects of postharvest $CaCl_2$ applications on the firmness-water relations, cell wall calcium levels, and postharvest life of the apple. It was reported that $CaCl_2$ had positive effects on minimizing salt-related damage to the fruit of the 'G. Delicious' apple cultivar and preserving fruit-water relationships and postharvest life.

Table 1. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on the weight loss (%) of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars

Cultivar	Application	Storage period (months) 1	2	3	4	5	6
'S. Delicious'	$CaCl_2.2H_2O$**	c0.68Cc*	a1.54BCb	a1.60BCb	a2.20Bd	a3.40Ab	a3.80Ab
	REO***	b1.39Ca	b1.20Cc	a1.40Cc	a2.63Bb	a3.20ABc	a4.03Aa
	$CaCl_2.2H_2O$+REO	b1.40Ba	b1.43Bb	b1.40Bc	b2.40ABc	b2.40ABd	b2.59Ac
	Control	a1.13Cb	a2.55Ba	a2.44Ba	a3.60Aa	a3.79Aa	a4.13Aa
'G. Delicious'	$CaCl_2.2H_2O$	a1.23Ac	c0.90Aab	c0.97Aab	b0.77Ac	c0.97Ab	c1.04Ab
	REO	a2.06Aa	c1.00Ba	b0.93Bb	c1.13ABb	c0.93Bb	c0.80Bc
	$CaCl_2.2H_2O$+REO	a1.60Ab	c0.80Ab	c1.08Aa	c0.76Ac	c1.30Aa	c1.33Aa
	Control	b0.67Bd	c0.87Bab	c0.74Bc	b2.81Aa	c0.87Bb	c1.31Ba
'G. Smith'	$CaCl_2.2H_2O$	b1.03Cc	b1.23BCd	b1.20BCc	a2.20ABb	b2.20ABc	b2.40Ab
	REO	a2.13ABa	a1.60Bb	a1.41Bb	b2.20ABb	b2.80Aa	b3.00Aa
	$CaCl_2.2H_2O$+REO	a1.56Bb	a2.00ABa	a1.60Ba	a2.60ABa	a2.80Aa	a3.01Aa
	Control	b0.60Cd	b1.40ABc	b1.60ABa	c2.00Ac	b2.40Ab	b2.40Ab

*Uppercase letters on the right side of the numbers indicate the difference between each cultivar x treatment combination for storage period; right lowercase letters indicate the difference between each cultivar x storage period combination for treatments; left lowercase letters indicate the difference between each treatment x storage period combination for cultivars. **$CaCl_2.2H_2O$: Calcium chloride dihydrate, *** REO: Rosehip essential oil

Fruit flesh firmness (FFF)

Fruit texture is one of the important quality characteristics of horticultural crops (Sati and Qubaj, 2021). Fruit freshness is generally reported to be directly proportional to the firmness value (Amin, 2016) and firmness is a critical factor affecting customers' decision to purchase apple fruit (Amin, 2016; Singh et al., 2022). In 'S. Delicious' and 'G. Delicious' cultivars, the highest FFF (31.14 N and 26.69 N) was obtained from REO. In the 'G. Smith', the $CaCl_2.2H_2O$ had a slightly higher FFF than the others. In general, REO maintained FFF better than the other treatments, followed by $CaCl_2.2H_2O$. It is concluded that the reason for the obtained results could be related to the effect of REO acting like a modified atmosphere around the apple fruit as well as the protection attribute of the $CaCl_2.2H_2O$ on the cell integrity of the fruit (Table 2). Chardonnet et al. (2003) reported that $CaCl_2$ infiltration provides an increase in both total and cell wall-bound Ca in apple tissue during storage and reaches its maximum with $CaCl_2$ application in fruit stored for 4 or 6 months, thus protecting the cell wall. Similar to our findings, Shirzadeh et al. (2011), Salem and Moussa (2014), Gago et al. (2016), and Gemeda (2021) reported positive effects of postharvest $CaCl_2$ applications on apple fruit.

Positive effects were reported in some previous research such as Serrano et al. (2005) in postharvest treatments of eugenol, thymol, menthol and eucalyptol, Shirzadeh and Kazemi (2012) in essential oil treatments of thyme and lavender, Paladines et al. (2014) in REO combined with *Aloe vera* gel on peach, nectarine, plum and sweet cherry, Öztürk et al. (2018) in *Aloe vera* treatments in 'Piraziz' apple cultivar, Amin (2016) in essential oil treatments on apple cv. of 'Anna', Martínez-Romero et al. (2017) in REO combined with *Aloe vera* or *Aloe arborescens* gels in plum fruit, Mahmoud et al. (2019) in essential oil applications in apple cv. of 'Anna'. Similarly, Martínez-Romero et al. (2019) reported higher firmness values in REO coated plum fruit during storage at room conditions. Singh et al. (2022) reported that applying REO combined with *Aloe vera* gel in the form of edible coating in pomegranate arils had higher firmness values than those without treatment.

The study findings displayed a correlation between fruit flesh firmness and weight loss. In particular, apples with firmer textures experienced lower weight loss rates. Wei et al. (2010) reported that enzymes affecting cell wall structure in apples play an important role in fruit softening, and found β-Gal and α-L-Af more effective than polygalacturonase and pectin methyl esterase on the storage period and quality of apples, especially when ripening and softening begins. Likewise, Shirzadeh et al. (2011) found successful postharvest Ca applications to prevent fruit softening and reduce weight loss. In this study, the FFF decreased in all treatments with increasing storage period (Table 2). Similarly, Shirzadeh et al. (2011), Hussain et al. (2012), Paladines et al. (2014), Salem and Moussa (2014), Amin (2016), Gago et al. (2016), Martínez-Romero et al. (2017), AL-Saikhan (2018), Mahmoud et al. (2019), Martínez-Romero et al. (2019), Gemeda (2021), Mazumder et al. (2021), Sati and Qubbaj (2021) and Singh et al. (2022) reported a decreasing in FFF during storage in different fruit cultivars treated with $CaCl_2$ and essential oils.

Titratable acidity (TA) and pH

TA is one of the most important parameters in evaluating fruit quality during storage, and low TA indicates accelerated senescence (Sati and Qubbaj, 2021). In the 'S. Delicious' the treatment with the lowest TA loss

Table 2. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on the fruit flesh firmness (N) of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars

Cultivar	Storage period (months)							
	Application	0	1	2	3	4	5	6
'S. Delicious'	$CaCl_2.2H_2O$**	a84.52Aa*	B71.17Bb	A75.62ABa	B66.72BCa	b57.83Ca	c26.69Da	Ab26.69Dab
	REO***	A75.62Aa	B71.17Aa	B66.72Aab	Ab71.17Aab	b66.72Aa	B26.69Ba	A31.14Ba
	$CaCl_2.2H_2O$+REO	A80.07Aa	B75.62ABab	B66.72Cb	b66.72BCab	b66.72Ca	a31.14Da	b22.24Db
	Control	A80.07Aa	A75.62Ab	B62.28Bb	b57.83Bb	b57.83Ba	a35.59Ca	A26.69Cab
'G. Delicious'	$CaCl_2.2H_2O$	B57.83BCb	B75.62Aa	B62.28Ba	c53.38CDb	c44.48Dc	A48.93CDa	B17.79Ea
	REO	A80.07Aa	C62.28Cbc	B66.72BCa	b62.28BCa	ab75.62ABa	B26.69Db	B26.69Da
	$CaCl_2.2H_2O$+REO	B71.17Aa	C62.28Ac	C48.93Bb	c40.03Bc	c44.48Cc	B17.79Cb	B17.79Ca
	Control	A75.62Aa	A71.17ABab	B62.28Ca	b57.83Cab	b62.28BCb	B22.24Db	A22.24Da
'G. Smith'	$CaCl_2.2H_2O$	A84.52Ba	A97.86Aa	A80.07Ba	a84.52Ba	a80.07Ba	B40.03Ca	A31.14Ca
	REO	A80.07Ba	A97.86Aa	A75.62Ba	a80.07Ba	a80.07Ba	A35.59Ca	A31.14Ca
	$CaCl_2.2H_2O$+REO	A84.52ABa	A84.52Ab	A75.62Ba	a84.52ABa	a88.96Aa	a35.59Ca	a31.14Ca
	Control	A75.62Ba	A75.62Bc	A80.07ABa	a81.76ABa	a19.8384.52Aa	A35.59Ca	a31.14Ca

*Uppercase letters on the right side of the numbers indicate the difference between each cultivar x treatment combination for storage period; right lowercase letters indicate the difference between each cultivar x storage period combination for treatments; left lowercase letters indicate the difference between each treatment x storage period combination for cultivars. **$CaCl_2.2H_2O$: Calcium chloride dihydrate, *** REO: Rosehip essential oil

(9.4%) during storage was $CaCl_2.2H_2O$, followed by REO (12.1%) at the end of the storage. In the 'G. Delicious' the treatment with the lowest TA loss was REO (21.3%) at the end of the storage. In the 'G. Smith' TA increased in all treatments during storage and the highest value was in REO followed by $CaCl_2.2H_2O$+REO (Table 3). Consumers prefer apples that meet certain quality criteria, including maintaining fruit titratable acidity. Treatments have proven effective in achieving this, likely through a decrease in fruit respiration rate. This decrease leads to less organic acid consumption, thereby preserving fruit acidity during storage better than untreated samples. According to Reyes-Medina et al. (2017), applying $CaCl_2$ can delay ripening and prevent fruit from spoiling. According to Fidler (1973), storage of most apple cultivars at relatively high CO_2 concentrations combined with low oxygen delays TA loss (Argenta et al., 2000). It is thought that REO acted like an modified atmosphere surrounding the fruit and maintained the TA thanks to slowing down the metabolic process. Similar findings reported in previous researches of Rabiei et al. (2011), Shirzadeh et al. (2011), Hussain et al. (2012), Paladines et al. (2014), Salem and Moussa (2014), Amin (2016), Gago et al. (2016), Martínez-Romero et al. (2017), AL- Saikhan (2018), Martínez-Romero et al. (2019), Hussain et al. (2019), Gemeda (2021), Mazumder et al. (2021), Sati and Qubbaj (2021) and Singh et al. (2022).

The pH contents of 'S. Delicious' and 'G. Delicious' increased during storage compared to the initial values. At the end of storage, the highest (4.07) pH was recorded in REO, and the treatment with the highest pH increase (8.82%) at the end of storage compared to the initial values was REO, followed by $CaCl_2.2H_2O$+REO (7.30%). At the end of storage, the highest pH content (3.97) was recorded in REO, and the treatment with the highest pH increase (7.87%) at the end of storage compared to the initial values was control. In 'G. Smith' cultivar, pH contents increased in $CaCl_2.2H_2O$ during storage compared to the initial values, while there was a slight decrease in the other treatments, and the highest (3.36) pH content at the end of storage was recorded in the control. REO was more effective in 'S. Delicious' and 'G. Delicious', in maintaining the pH content of the fruit, while in 'G. Smith', $CaCl_2.2H_2O$ had a higher pH than the initial values of other treatments. However, the effects of treatments on the pH of cultivars were not statistically significant during storage (Table 3). Shirzadeh et al. (2011) and Tamalea et al. (2021) reported that postharvest $CaCl_2$ application did not have any effect on the pH of fruit. Singh et al. (2022) reported that pomegranate arils treated with REO had higher pH content than those treated with *Aloe vera* gel.

Soluble solids content (SSC)

The soluble solids content (SSC) of fruit is a good index for determining fruit quality and ripeness, and SSC increases with ripeness (Sati and Qubbaj, 2021). The increase in SSC is attributed to the enzymatic conversion of higher polysaccharides such as starches and pectins to simple sugars during ripening (Gemeda, 2021). The SSC increased in the 'S. Delicious' cultivar compared to the initial values, with the highest increase (51.44%) in the control group. In 'G. Delicious', an increase was recorded compared to the initial values except for $CaCl_2.2H_2O$+REO, and the highest (12.19 Brix°) SSC was recorded in the control at the end of the storage. In the 'G. Smith', SSC increased during storage compared to the initial value (Table 4).

Similar to the findings obtained in this study in 'S. Delicious' and 'G. Delicious', Hussain et al. (2012) reported that postharvest $CaCl_2$ treatment had a lower SSC than

Table 3. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on the titratable acidity (mg malic acid/100 mL) and pH of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars

Cultivar	Application	TA - Storage period (months) 0	1	2	3	4	5	6
'S. Delicious'	$CaCl_2.2H_2O$**	c0.317Ba*	c0.440Aef	c0.301Ba	c0.321Ba	c0.324Bb	c0.272Ba	c0.291Ba
	REO***	c0.325ABa	c0.379Aa	c0.262BCa	b0.293BCa	c0.322ABab	c0.248Ca	c0.290BCa
	$CaCl_2.2H_2O$+REO	c0.327BCa	c0.403Aa	c0.295BCa	c0.301BCa	b0.352ABa	c0.266Ca	b0.273Ca
	Control	c0.353Aa	c0.356Aab	c0.266Ba	b0.294ABa	c0.347Aa	c0.233Ba	b0.270Ba
'G. Delicious'	$CaCl_2.2H_2O$	b0.686Aa	b0.633Aa	b0.418BCa	b0.415BCa	b0.470Ba	b0.356Cb	b0.388Cb
	REO	b0.612Ab	b0.519Bb	b0.426Ca	b0.325Db	b0.474BCa	b0.414Ca	b0.478BCa
	$CaCl_2.2H_2O$+REO	b0.613Ab	b0.506Bb	b0.407Ca	b0.391CDa	b0.341Dc	b0.374CDab	b0.314Dc
	Control	Bb0.576Ab	b0.643Aa	b0.336Cb	b0.325Cb	b0.411Bb	b0.404Bab	b0.321Cc
'G. Smith	$CaCl_2.2H_2O$	a0.104Ac	a0.852Ca	a0.909BCb	a0.935Ba	a0.986Ba	a0.709Db	a0.623Ec
	REO	a0.125A	a0.884Ca	a0.951Bb	a0.845CDb	a0.790DEb	a0.744EFab	a0.709Fa
	$CaCl_2.2H_2O$+REO	a0.143Aa	a0.884Ca	a0.103Ba	a0.908Ca	a0.906Ca	a0.801Da	a0.692Eab
	Control	a0.121A	a0.789Cb	a0.894Bb	a0.931Ba	a0.751CDb	a0.704DEb	a0.645Ebc

Cultivar	Application	pH - Storage period (months) 0	1	2	3	4	5	6
'S. Delicious'	$CaCl_2.2H_2O$**	B3.75Ba*	a4.01ABa	a3.90ABa	a4.02ABa	b4.07ABa	a4.15Aa	a3.94ABa
	REO***	a3.74Ba	a4.10Aa	a3.94ABa	a4.03ABa	a4.20Aa	a4.10Aa	a4.07ABa
	$CaCl_2.2H_2O$+REO	a3.70Ba	a4.14Aa	a4.11Aa	a4.02ABa	a4.11Aa	a4.05Aa	a3.97ABa
	Control	a3.77Ba	a4.20Aa	a4.09ABa	A3.94ABa	a4.05ABa	a4.25Aa	a3.94ABa
'G. Delicous'	$CaCl_2.2H_2O$	a3.77Ba	a4.20Aa	a4.09ABa	a3.94ABa	a4.05ABa	a4.25Aa	a3.94ABa
	REO	a3.70Ba	a4.14Aa	a4.11Aa	a4.02ABa	a4.11Aa	a4.05Aa	a3.97ABa
	$CaCl_2.2H_2O$+REO	b3.75Ba	a4.01ABa	a3.90ABa	a4.02ABa	b4.07ABa	a4.15Aa	a3.94ABa
	Control	ab3.56BCb	ab3.71ABa	b3.81ABa	a4.03ABa	a3.90ABa	b3.28Cb	a3.84ABa
'G. Smith'	$CaCl_2.2H_2O$	b3.27Ba	b3.26Ba	b3.35Ba	a3.36Aa	b3.25Ba	c3.24Ba	b3.34Aa
	REO	c3.37Aa	b3.28Aa	c3.42Aa	c3.41Aa	b3.27Aa	c3.29Aa	c3.14Ba
	$CaCl_2.2H_2O$+REO	C3.34ABa	c3.25Ba	b3.38ABa	b3.66Aa	b3.16Ba	b3.31Ba	c3.27Ba
	Control	b3.45Aa	c3.29Aa	b3.42Aa	b3.43Aa	b3.18Aa	b3.14Aa	b3.36Aa

*Uppercase letters on the right side of the numbers indicate the difference between each cultivar x treatment combination for storage period, right lowercase letters indicate the difference between each cultivar x storage period combination for treatments, left lowercase letters indicate the difference between each treatment x storage period combination for cultivars. **$CaCl_2.2H_2O$: Calcium chloride dihydrate, *** REO: Rosehip essential oil

the control in the 'Red Delicious' cultivar. Similarly, Sati and Qubbaj (2021) reported that $CaCl_2$, gum arabic+$CaCl_2$ and cactus mucilage+$CaCl_2$ treatments effectively maintained the SSC of tomato fruit during storage. Shirzadeh et al. (2011) reported that postharvest $CaCl_2$ treatment preserved SSC in the 'Jonagold' cultivar. Gago et al. (2016) found effective the $CaCl_2$ in preserving SSC in 'G. Delicious'. Salem and Moussa (2014) reported an insignificant effect of postharvest $CaCl_2$ treatment on SSC in the apple cv. of 'Anna'. Gemeda (2021) reported a higher SSC in postharvest $CaCl_2$ treatments compared to the control similar to the findings obtained in this study in 'G. Smith'. Hussain et al. (2019) reported a higher SSC in postharvest $CaCl_2$ treated pear fruit than in the control. Similar to the 'S. Delicious' cultivar in this study, Amin (2016) reported a higher SSC in the essential oil treated 'Anna' cultivar compared to the control.

Similar to the 'G. Delicious' in this study, Martínez-Romero et al. (2019) reported higher values of ripeness index in plums in the postharvest REO treatment compared to the control. Paladines et al. (2014) reported a higher ripeness index in the control group of peach, nectarine, plum and sweet cherry compared to postharvest treatment of *Aloe vera* gel+REO. Singh et al. (2022) found successful the REO+*Aloe vera* gel treatment in the preservation of SSC better than control in the pomegranate arils. With extending storage period, an increase was recorded in the SSC of the fruit in all treatments. Similarly, Shirzadeh et al. (2011), Hussain et al. (2012), Paladines et al. (2014), Amin (2016), Gago et al. (2016), Martínez-Romero et al. (2017), AL-Saikhan (2018), Martínez-Romero et al. (2019), Hussain et al. (2019), Gemeda (2021), Sati and Qubbaj (2021) and Singh et al. (2022) reported an increase in SSC during storage.

Respiration rate (RR)

Respiration metabolism is known to be a normal process in the postharvest life of fruit, mainly consuming

Table 4. The effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on the soluble solids content (Brix°) of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars

Cultivar	Application	Storage period (months) 0	1	2	3	4	5	6
'S. Delicious'	$CaCl_2.2H_2O$**	b8.63Db*	a12.20Aa	a11.93Aba	a12.00ABa	b12.10Aab	b11.03BCc	b10.76Cb
	REO***	a10.30CDa	b10.03Dc	a11.20BCa	a11.10BCb	a12.53Aa	a12.26Aab	a12.00ABa
	$CaCl_2.2H_2O$+REO	b10.36Ea	a10.70DEbc	a11.93ABCa	a11.43CDab	a12.50ABa	a12.86Aa	a11.73BCa
	Control	c7.66Bc	b10.83Ab	b11.83Aa	b11.43Aab	b11.70Ab	a11.70Abc	a11.60Aa
'G. Delicious'	$CaCl_2.2H_2O$	a9.56Db	b11.40BCb	b10.30Db	b10.53CDb	a13.06Aa	a11.80Ba	a11.63Ba
	REO	ab10.00Bb	a10.76ABb	b8.39Cc	a10.60ABb	b10.96ABb	ab11.60Aa	ab11.53Aa
	$CaCl_2.2H_2O$+REO	a11.66Aa	a10.96ABb	b10.53Bb	a11.26ABb	b10.50Bb	c10.43Bb	b10.80ABb
	Control	a11.13Ea	a13.40ABa	a13.90Aa	a13.20ABC	a12.83BCa	a11.80DEa	a12.19CDa
'G. Smith'	$CaCl_2.2H_2O$	c7.33Cb	b11.43ABa	a11.60Aa	a11.33ABa	c10.76ABa	b10.46Bb	a11.60Aa
	REO	b9.53Ba	a10.83Aab	a11.03Aab	a11.06Aa	b11.43Aa	b11.40Aa	b11.16Aa
	$CaCl_2.2H_2O$+REO	c9.63Ba	a10.43ABbc	b10.60ABb	a11.23Aa	b10.73Aab	b11.30Aa	ab11.06Aa
	Control	b9.39Ca	c10.00BCc	b11.23Aab	b11.23Aa	c10.50ABb	b10.36ABC	b10.09BCb

*Uppercase letters on the right side of the numbers indicate the difference between each cultivar x treatment combination for storage period, right lowercase letters indicate the difference between each cultivar x storage period combination for treatments, left lowercase letters indicate the difference between each treatment x storage period combination for cultivars. **$CaCl_2.2H_2O$: Calcium chloride dihydrate, *** REO: Rosehip essential oil

carbohydrates, and organic acids, leading to weight loss and quality deterioration. Respiration metabolism is also accompanied by ethylene production and causes fruit senescence. This means that a lower RR and ethylene production may play an important role in better preservation of fruit quality (Fan et al., 2022). At the end of storage, the lowest RR (43.02 µLCO_2/kg.h) was in REO and the highest RR (50.56 µLCO_2/kg.h) was recorded in the control group in 'S. Delicious'. The lowest RR, at the end of storage, in 'G. Delicious' was in $CaCl_2.2H_2O$+REO (35.27 µLCO_2/kg.h), followed by REO with 39.16 µLCO_2 / kg.h. In 'G. Smith', the lowest RR at the end of storage was in the control with 58.407 µLCO_2/kg.h, followed by REO with 58.501 µLCO_2/kg.h. In general, it can be said that REO and $CaCl_2.2H_2O$+REO were more successful treatments in suppressing the RR of the fruit. Hussain et al. (2012), Gemeda (2021) and Mazumder et al. (2021) reported a positive effect of postharvest $CaCl_2$ applications on the suppression of RR during storage. According to Paladines et al. (2014), Martínez-Romero et al. (2017) and Singh et al. (2022), REO+*Aloe vera* gel had lower RR than the control. Similarly, Martínez- Romero et al. (2019) reported that REO exhibited lower RR than the control. Similar to Mazumder et al. (2021), it was observed in this study that the RRs of fruit increased in all treatments with an extended storage period (Table 5).

Ethylene production (EP)

Ethylene is considered as the main ripening stimulant synthesized during the ripening stage of fruit under growing or storage conditions (Mazumder et al., 2021). EP increased during storage in the 'S. Delicious' cultivar. At the end of storage, the lowest EP was recorded in REO with 11.473 µLC_2H_4/kg.h and the highest EP was in the control group with 44.331 µLC_2H_4/kg.h. In the 'S. Delicious', the EP of the fruit treated with REO was significantly lower than the other treatments, therefore, it can be said that REO was quite successful in suppressing EP for this apple cultivar compared to other treatments. 'G. Delicious' showed an increase in EP at the end of storage. The lowest EP was obtained in REO with 3.156 µLC_2H_4/ kg.h, followed by $CaCl_2.2H_2O$+REO with 24.282 µLC_2H_4/ kg.h at the end of storage. As in the 'S. Delicious', it was noted that the EP of REO-treated fruit was significantly lower than the other treatments in the 'G. Delicious'. Therefore, it can be said that for the 'G. Delicious', REO successfully suppressed the EP of the fruit compared to the other treatments. In 'G. Smith', EP generally increased during storage. At the end of storage, the lowest EP was recorded in REO with 0.442 µLC_2H_4/kg.h, followed by $CaCl_2.2H_2O$ with 2.716 µLC_2H_4/kg.h. At the end of storage, the highest EP was recorded in the control group with 4.300 µLC_2H_4/kg.h. As in the case of 'S. Delicious' and 'G. Delicious', it was noted that the EP of the REO-treated fruit was significantly lower than the other treatments in the 'G. Smith'. Therefore, it can be said that for 'G. Smith' as well, REO was quite successful in suppressing the EP of the fruit compared to the other treatments. REO was the most effective treatment in suppressing EP in all cultivars, followed by $CaCl_2.2H_2O$+REO at the end of storage (Table 6).

Shirzadeh et al. (2011) and Mazumder et al. (2021) found successful postharvest application of $CaCl_2$ in effectively reducing EP during storage. Rabiei et al. (2011) reported that postharvest application of thyme and lavender essential oils had positive effects on the suppression of EP during storage. Shirzadeh and Kazemi (2012) reported that postharvest application of thyme essential oil had positive effects on the suppression of EP during storage, while postharvest application of Ca was found

Table 5. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on respiration rate (μLCO_2/kg.h) of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars

Cultivar		Storage period (months)		
	Application	1	3	6
'S. Delicious'	$CaCl_2.2H_2O$**	a50.48Ab*	a33.37Ba	b47.82Aa
	REO***	a49.76Ab	a24.76Ba	b43.02Aa
	$CaCl_2.2H_2O$+REO	a43.90Ab	a30.34Ba	b48.57Aa
	Control	a67.32Aa	b30.87Ca	ab50.56Ba
'G. Delicious'	$CaCl_2.2H_2O$	b6.01Cc	a26.24Bb	a62.50Aa
	REO	a50.74Aa	a29.77Bb	b39.16Ab
	$CaCl_2.2H_2O$+REO	a37.24Ab	a27.12Bb	b35.27Bb
	Control	c8.52Bc	a40.96Aa	b42.08Ab
'G. Smith'	$CaCl_2.2H_2O$	a45.07Bab	a27.67Ca	a61.77Ab
	REO	a52.89Aab	a22.53Ba	a58.50Ab
	$CaCl_2.2H_2O$+REO	a43.32Bb	a23.51Ca	a77.89Aa
	Control	b55.34Aa	b26.48Ba	a58.41Ab

*Capital letters on the right side of the numbers denote the difference between each cultivar x treatment combination in terms of storage time, right lower case letters denote the difference between each cultivar x storage time combination in terms of treatment, left lower case letters denote the difference between each cultivar x storage time combination in terms of the cultivar. **$CaCl_2.2H_2O$: Calcium chloride dihydrate, ***REO: Rosehip essential oil

Table 6. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on ethylene production (μLC_2H_4/kg.h) of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars

Cultivar		Storage period (months)		
	Application	1	3	6
'S. Delicious'	$CaCl_2.2H_2O$**	5.537	16.499	27.777
	REO***	5.285	3.557	11.473
	$CaCl_2.2H_2O$+REO	0.014	15.117	32.345
	Control	12.923	16.076	44.331
'G. Delicious'	$CaCl_2.2H_2O$	25.405	19.280	33.601
	REO	0.013	4.534	3.156
	$CaCl_2.2H_2O$+REO	15.303	22.378	24.282
	Control	25.118	31.177	28.059
'G. Smith'	$CaCl_2.2H_2O$	0.017	4.948	2.716
	REO	0.012	1.167	0.442
	$CaCl_2.2H_2O$+REO	0.015	3.201	3.437
	Control	0.007	4.966	4.300

$CaCl_2.2H_2O$: Calcium chloride dihydrate,*REO: Rosehip essential oil

more effective than lavender essential oil. Paladines et al. (2014) indicated that REO combined with *Aloe vera* gel effectively reduced the EP of peach, nectarine, and plum fruit during storage. Singh et al. (2022) stated that the EP of pomegranate arils treated with an edible coating of *Aloe vera* gel combined with REO was lower than those without treatment. Martínez-Romero et al. (2017) reported that the application of REO combined with *Aloe vera* or *Aloe arborescens* gels was effective in delaying the EP of plum fruit during storage, and the EP of treated fruit was lower than the control group. Martínez-Romero et al. (2019) stated that the EP of plum fruit coated with REO was significantly lower during storage compared to the control group. In this study, an increase was found in the EP in all apple cultivars and postharvest treatments during storage. Similar to our findings, Mazumder et al. (2021) and Singh et al. (2022) reported an increase in the EP of fruit with an extended storage period.

According to the Kruskal-Wallis test results, when the effects of $CaCl_2.2H_2O$, REO and $CaCl_2.2H_2O$+REO combined treatments on the EP of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars were evaluated according to the cultivar x month and application x month combination, the difference between the rank means of the months was statistically significant ($P<0.05$) The difference between the first and sixth month EP was not statistically significant, while the third month EP was lower than these two months and statistically significant ($P<0.05$) (Table 7).

Fruit color (FC)

Postharvest fruit quality is influenced by various quality

Table 7. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on ethylene production (µLC_2H_{24}/kg.h) of fruit during storage according to cultivar x month and application x month combination in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars according to the Kruskal-Wallis test

Cultivar	By cultivar x month combination			
	Storage period (months)			
	Application	**1**	**3**	**6**
'S. Delicious'	$CaCl_2.2H_2O$**	2C*	5B	8A
	REO***	5.66A	2B	7.33A
	$CaCl_2.2H_2O$+REO	2C	5B	8A
	Control	2.66C	4.3B	8A
'G. Delicious'	$CaCl_2.2H_2O$	5B	2C	8A
	REO	2C	5B	8A
	$CaCl_2.2H_2O$+REO	5B	8A	2C
	Control	2.33	7.67	5.00
'G. Smith'	$CaCl_2.2H_2O$	2C	8A	5B
	REO	2B	7.33A	5.66A
	$CaCl_2.2H_2O$+REO	2C	5B	8A
	Control	2.00	7.00	6.00
Cultivar	**By application x month combination**			
	Storage period (months)			
	Application	**1**	**3**	**6**
'S. Delicious'	$CaCl_2.2H_2O$**	4.6B*	2B	2C
	REO***	10A	6A	9A
	$CaCl_2.2H_2O$+REO	2.3B	8A	5B
	Control	9A	10A	10A
'G. Delicious'	$CaCl_2.2H_2O$	10.33A	5.66B	11A
	REO	2C	2C	5C
	$CaCl_2.2H_2O$+REO	5B	7.33B	2D
	Control	8.6A	11A	8B
'G. Smith'	$CaCl_2.2H_2O$	10.16A	9.3A	5B
	REO	5B	2C	2C
	$CaCl_2.2H_2O$+REO	8.83A	5B	9A
	Control	2C	9.66A	10A

*According to the Kruskal-Wallis test, capital letters indicate differences between cultivars in each treatment x month combination. **$CaCl_2.2H_2O$: Calcium chloride dihydrate, ***REO: Rosehip essential oil

attributes such as weight loss, firmness, SSC and TA as well as color and their changes during storage (Paladines et al., 2014). In the 'S. Delicious' cultivar, fruit brightness (L^*) increased in all treatments except $CaCl_2.2H_2O$+REO. The highest increase of 19.5% compared to the beginning was realized in $CaCl_2.2H_2O$, followed by REO with 18.2% and control with 8%. In $CaCl_2.2H_2O$+REO, fruit brightness decreased by 11.5%. REO was the treatment that best preserved FC and vividness of FC with the highest Hue angle (h°) (212.33) and Chroma (C^*) values (31.17). In 'G. Delicious', brightness increased in all treatments except for $CaCl_2.2H_2O$+REO compared to the beginning. The highest increase was recorded in REO with 5.1%, while there was a 1% decrease in $CaCl_2.2H_2O$+REO (Table 8). h° and C^* were highest in the control group (107.36 and 47.99, respectively), followed by $CaCl_2.2H_2O$+REO (106.91 and 47.73, respectively). According to these data, control and $CaCl_2.2H_2O$+REO were the treatments in which FC and vividness of FC of the 'G. Delicious' were best preserved (data not presented in the table). In this cultivar, staining on the peel towards the end of storage, especially in the $CaCl_2.2H_2O$, is thought to be caused by the treatment.

Gago et al. (2016) and Tamalea et al. (2021) reported that postharvest $CaCl_2$ positively affected FC. In the 'G. Smith' cultivar, a slight decrease in brightness was recorded in all treatments except REO compared to the beginning. In REO, fruit brightness increased by

Table 8. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on fruit color (CIE L*a*b*) during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars

Cultivar	Application	Storage period (months) 0	1	2	3	4	5	6
				L*				
'S. Delicious'	$CaCl_2.2H_2O$**	32.57a*	40.56a	40.56a	35.19a	40.21a	39.04a	38.92a
	REO***	32.94a	36.47a	35.15a	33.85a	35.08a	32.54a	38.92a
	$CaCl_2.2H_2O$+REO	36.45a	33.30a	33.64a	36.66a	36.42a	35.13a	32.26a
	Control	37.76a	35.09a	35.59a	36.03a	40.34a	35.84a	40.78a
'G. Delicious'	$CaCl_2.2H_2O$	76.37a	76.29a	76.00a	71.23a	78.36a	78.78a	77.90a
	REO	71.32a	70.93a	71.73a	71.12a	72.37a	71.22a	74.97a
	$CaCl_2.2H_2O$+REO	76.99a	76.13a	76.28a	76.56a	77.20a	77.39a	76.23a
	Control	77.04a	75.78a	76.50a	76.03a	76.59a	75.88a	78.76a
'G. Smith'	$CaCl_2.2H_2O$	68.37a	65.23a	61.21a	68.35a	65.20a	67.45a	67.04a
	REO	64.65a	64.79a	67.49a	66.03a	65.06a	65.79a	68.61a
	$CaCl_2.2H_2O$+REO	69.04a	67.02a	65.54a	66.19a	69.62a	66.02a	65.59a
	Control	68.48a	68.04a	66.04a	68.39a	68.10a	68.00a	65.89a
				a*				
'S. Delicious'	$CaCl_2.2H_2O$**	27.28a	30.64a	30.64a	26.90a	29.38a	27.47a	26.90a
	REO***	27.33a	28.82a	29.04a	26.96a	28.07a	29.44a	26.34a
	$CaCl_2.2H_2O$+REO	30.62a	27.30a	25.41a	28.88a	28.31a	28.88a	25.39a
	Control	25.39a	29.09a	28.04a	25.07a	26.01a	29.80a	25.43a
'G. Delicious'	$CaCl_2.2H_2O$	-13.47a	-14.40a	-13.36a	-13.66a	-13.72a	-12.15a	-6.75a
	REO	-16.07a	-16.19a	-14.06a	-13.89a	-15.42a	-12.78a	-13.03a
	$CaCl_2.2H_2O$+REO	-16.98a	-16.32a	-16.19a	-16.65a	-16.46a	-15.41a	-13.88a
	Control	-15.18a	-15.13a	-13.90a	-15.44a	-13.55a	-14.00a	-14.32a
'G. Smith'	$CaCl_2.2H_2O$	-21.44a	-21.55a	-20.86a	-20.69a	-20.35a	-18.53a	-15.40a
	REO	-21.69a	-20.80a	-20.78a	-20.77a	-19.10a	-18.14a	-18.61a
	$CaCl_2.2H_2O$+REO	-21.58a	-20.24a	-21.02a	-20.21a	-18.96a	-19.71a	-16.76a
	Control	-21.94a	-21.06a	-20.97a	-19.55a	-17.32a	-17.40a	-14.57a
				b*				
'S. Delicious'	$CaCl_2.2H_2O$**	12.14a	16.45a	16.45a	14.16a	18.10a	16.45a	15.36a
	REO***	12.64a	15.13a	14.33a	12.92a	14.40a	14.40a	16.67a
	$CaCl_2.2H_2O$+REO	16.07a	12.87a	13.08a	22.39a	16.45a	14.16a	10.81a
	Control	15.38a	14.51a	14.91a	12.95a	17.18a	12.69a	15.02a
'G. Delicious'	$CaCl_2.2H_2O$	42.47a	42.90a	42.77a	41.76a	45.07a	49.10a	45.41a
	REO	41.51a	40.62a	41.85a	41.32a	42.41a	45.08a	43.97a
	$CaCl_2.2H_2O$+REO	45.62a	43.71a	44.38a	44.66a	45.39a	46.22a	45.67a
	Control	42.16a	41.64a	42.29a	43.49a	45.02a	47.35a	45.80a
'G. Smith'	$CaCl_2.2H_2O$	40.97a	41.35a	41.92a	42.17a	40.96a	41.28a	42.48a
	REO	39.53a	39.03a	41.18a	41.70a	39.85a	40.01a	41.28a
	$CaCl_2.2H_2O$+REO	42.74a	43.06a	40.77a	41.76a	40.22a	40.84a	41.71a
	Control	42.47a	42.21a	40.69a	42.71a	41.90a	41.29a	39.58a

*Lowercase letters indicate the difference between treatments in each cultivar x storage time combination. **$CaCl_2.2H_2O$: Calcium chloride dihydrate, ***REO: Rosehip essential oil

6.1% at the end of storage compared to the beginning. There was a 1.9% decrease in brightness at the end of storage in $CaCl_2.2H_2O$, a 3.8% decrease in control, and a 5% decrease in $CaCl_2.2H_2O$+REO. h° (114.27) and C* (45.28) were the highest in REO (data not presented in the table). According to these data, as in the 'S. Delicious' cv., REO was the treatment that best preserved the FC and vividness of FC of the 'G. Smith'. Paladines et al. (2014) reported that REO combined with *Aloe vera* gel delayed the color change of peach, nectarine, plum and sweet cherry fruit and a higher h° value was obtained compared to other treatments. Martínez-Romero et al. (2017) reported that the highest h° in plum fruit was obtained in fruit treated with REO after harvest. Similarly, Martínez-Romero et al. (2019) obtained higher h° values in plums treated with REO. Singh et al. (2022) reported that the color of pomegranate arils with REO+*Aloe vera* gel edible coating treatment was better preserved than those without treatment.

Table 9. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on fruit flesh color (CIE L*a*b*) during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars

Cultivar	Application	Storage period (months) 0	1	2	3	4	5	6
		L*						
'S. Delicious'	$CaCl_2.2H_2O$**	83.86a*	84.03a	82.70a	82.38a	81.80a	80.93a	81.31a
	REO***	83.20a	83.40a	83.65a	83.91a	80.95a	80.91a	80.98a
	$CaCl_2.2H_2O$+REO	83.81a	82.42a	83.62a	72.04a	79.11a	82.65a	80.98a
	Control	84.06a	81.85a	82.59a	82.23a	83.25a	81.41a	80.99a
'G. Delicious'	$CaCl_2.2H_2O$	81.92a	83.95a	83.97a	83.01a	83.44a	78.53a	81.49a
	REO	78.51a	82.93a	82.91a	83.19a	82.97a	84.04a	82.98a
	$CaCl_2.2H_2O$+REO	82.48a	83.94a	83.94a	83.68a	84.22a	84.91a	83.71a
	Control	82.48a	84.87a	84.87a	83.93a	85.19a	85.17a	82.99a
'G. Smith'	$CaCl_2.2H_2O$	81.67a	82.56a	82.10a	82.79a	81.43a	81.84a	80.22a
	REO	82.32a	82.83a	81.19a	82.05a	81.03a	82.20a	82.30a
	$CaCl_2.2H_2O$+REO	82.11a	83.13a	80.98a	82.77a	81.65a	80.98a	79.74a
	Control	82.30a	82.66a	82.19a	82.88a	82.25a	81.89a	80.61a
		a*						
'S. Delicious'	$CaCl_2.2H_2O$**	-9.64Aa	-9.34Aa	-9.74Aa	-8.43Aa	-8.17Aa	-8.43Aa	-8.62Aa
	REO***	-8.54Aa	-9.78Aa	-9.09Aa	-8.51Aa	-9.37Aa	-8.09Aa	-8.20Aa
	$CaCl_2.2H_2O$+REO	-9.05Aa	-9.31Aa	-8.91Aa	-8.66Aa	-7.29Aa	-8.50Aa	-8.69Aa
	Control	-7.77Aa	-8.86Aa	-8.08Aa	-8.98Aa	-7.99Aa	-8.57Aa	-8.75Aa
'G. Delicious'	$CaCl_2.2H_2O$	-7.05ABa	-9.48Aa	-9.48Aa	-8.22ABa	-8.19ABa	-7.78ABa	-6.75Ba
	REO	-7.38Aa	-8.06Aa	-8.06Aa	-8.29Aa	-8.18Aa	-9.59Aa	-8.27Aa
	$CaCl_2.2H_2O$+REO	-7.99Aa	-8.98Aa	-8.98Aa	-9.57Aa	-7.46Aa	-7.78Aa	-7.80Aa
	Control	-8.86Aa	-7.56Aa	-7.56Aa	-7.79Aa	-8.53Aa	-7.99Aa	-7.04Aa
'G. Smith'	$CaCl_2.2H_2O$	-13.35Aa	-11.72ABa	-9.11Ca	-9.57BCab	-10.00BCa	-7.73Ca	-9.23BCa
	REO	-12.28Aab	-10.17ABCab	-10.52ABCa	-11.19ABa	-9.26BCa	-9.13BCa	-8.42Ca
	$CaCl_2.2H_2O$+REO	-10.98Ab	-8.31Bb	-9.63ABa	-9.91ABab	-9.87ABa	-8.22Ba	-8.55ABa
	Control	-11.53Aab	-10.14ABab	-9.76ABa	-8.42Bb	-8.06Ba	-8.06Ba	-8.06Ba
		b*						
'S. Delicious'	$CaCl_2.2H_2O$**	26.06a	23.82a	26.75a	24.26a	23.68a	25.68a	27.60a
	REO***	24.71a	24.27a	23.35a	22.99a	23.96a	22.45a	26.28a
	$CaCl_2.2H_2O$+REO	24.26a	25.86a	23.00a	28.75a	24.72a	26.05a	29.48a
	Control	21.83a	27.83a	25.19a	27.03a	23.23a	23.15a	27.03a
'G. Delicious'	$CaCl_2.2H_2O$	22.46a	28.78a	28.78a	26.80a	26.95a	26.49a	26.47a
	REO	24.00a	28.92a	28.92a	26.47a	27.31a	26.55a	29.98a
	$CaCl_2.2H_2O$+REO	21.05a	26.68a	26.68a	26.52a	27.93a	25.24a	27.17a
	Control	26.18a	31.25a	31.25a	27.47a	31.82a	29.82a	26.54a
'G. Smith'	$CaCl_2.2H_2O$	25.29a	22.88a	18.87a	21.25a	20.51a	15.65a	22.67a
	REO	22.55a	19.25a	21.22a	22.03a	19.53a	19.58a	19.20a
	$CaCl_2.2H_2O$+REO	22.19a	15.37a	19.70a	20.11a	21.19a	17.97a	18.86a
	Control	21.32a	19.23a	18.68a	16.70a	17.44a	18.72a	20.91a

*Right uppercase letters denote the difference between each cultivar x treatment combination and storage time, right lowercase letters denote the difference between each cultivar x storage time combination. **$CaCl_2.2H_2O$: Calcium chloride dihydrate, ***REO: Rosehip essential oil

Table 10. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on the overall quality (points) of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars

Cultivar	Application	Storage period (months) 0	1	2	3	4	5	6	Mean
'S. Delicious'	$CaCl_2.2H_2O$**	9	9	9	9	9	8	8	8.71
	REO***	9	8.66	8.33	8.33	8	8	7.66	8.28
	$CaCl_2.2H_2O$+REO	9	9	9	9	8.33	8.33	8	8.66
	Control	9	9	9	9	8.33	8	7	8.47
'G. Delicious'	$CaCl_2.2H_2O$	9	9	9	9	9	7.66	7	8.52
	REO	9	8	7	5.66	5	4.33	4.33	6.18
	$CaCl_2.2H_2O$+REO	9	9	9	9	8.33	8.33	7.66	8.61
	Control	9	9	9	8.66	9	7.66	7.33	8.52
'G. Smith'	$CaCl_2.2H_2O$	9	9	9	9	8.66	7	7.33	8.42
	REO	9	9	9	9	9	8.66	8.66	8.90
	$CaCl_2.2H_2O$+REO	9	9	9	9	9	8.33	8	8.76
	Control	9	9	9	9	9	6.66	6.66	8.33

$CaCl_2.2H_2O$: Calcium chloride dihydrate,*REO: Rosehip essential oil

Table 11. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on the overall quality (points) of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars according to cultivar x month and application x month combination according to Kruskal-Wallis test result

Cultivar	Application	By cultivar x month combination, Storage period (months) 0	1	2	3	4	5	6
'S. Delicous'	$CaCl_2.2H_2O$**	14A*	14A	14A	14A	14A	3.5B	3.5B
	REO***	16.5A	13.16A	9.83AB	9.83AB	16.5A	6.5B	4.66B
	$CaCl_2.2H_2O$+REO	14.5A	14.5A	14.5A	14.5A	7.5B	7.5B	4B
	Control	15A	15A	15A	15A	9B	6B	2C
'G. Delicious'	$CaCl_2.2H_2O$	14A	14A	14A	14A	14A	4.5B	2.5C
	REO	20A	16.5AB	14.16B	10.5C	7.5CD	4.16D	4.16D
	$CaCl_2.2H_2O$+REO	14.5A	14.5A	14.5A	14.5A	7.83B	7.83B	3.33B
	Control	14.5A	14.5A	14.5A	11.5A	14.5A	4.33B	3.16B
'G. Smith'	$CaCl_2.2H_2O$	14.5A	14.5A	14.5A	14.5A	11.83	3B	4.16B
	REO	12.00	12.00	12.00	12.00	12.00	8.50	8.50
	$CaCl_2.2H_2O$+REO	13.5A	13.5A	13.5A	13.5A	13.5A	6.5B	3B
	Control	14A	14A	14A	14A	14A	3.5B	3.5B
Cultivar	**Application**	**By application x month combination, Storage period (months) 0**	**1**	**2**	**3**	**4**	**5**	**6**
'S. Delicous'	$CaCl_2.2H_2O$**	5.00	5.00	5.00	5.00	5.50	7.00	7.50
	REO***	5.00	5.50	5.166AB*	5.5A	6.5A	5.5A	5.33A
	$CaCl_2.2H_2O$+REO	5.00	5.00	5.00	5.00	4.00	5.00	5.5A
	Control	5.00	5.00	5.00	5.50	3.00	7.00	5.00
'G. Delicious'	$CaCl_2.2H_2O$	5.00	5.00	5.00	5.00	5.50	5.50	3.00
	REO	5.00	2.50	2.33B	2B	2B	2B	2B
	$CaCl_2.2H_2O$+REO	5.00	5.00	5.00	5.00	4.00	5.00	4B
	Control	5.00	5.00	5.00	4.00	6.00	5.67	6.33
'G. Smith'	$CaCl_2.2H_2O$	5.00	5.00	5.00	5.00	4.00	2.50	4.50
	REO	5.00	7.00	7.5A	7.5A	6.5A	7.5A	7.6A
	$CaCl_2.2H_2O$+REO	5.00	5.00	5.00	5.00	7.00	5.00	5.5A
	Control	5.00	5.00	5.00	5.50	6.00	2.33	3.67

*According to the Kruskal-Wallis test, capital letters indicate differences between cultivars in each cultivar x month and treatment x month combination. **$CaCl_2.2H_2O$: Calcium chloride dihydrate,*** REO: Rosehip essential oil

Fruit flesh color (FFC)

In the 'S. Delicious' cultivar, a slight decrease in brightness was recorded in all treatments at the end of storage compared to the beginning (Table 9). When the beginning (109.07) and end of storage (107.36) values of FFC values of h° were compared, the least change (1.56) was observed in the REO. $CaCl_2.2H_2O$+REO had the highest (30.73) C*. In the 'G. Delicious', brightness increased in all treatments except for $CaCl_2.2H_2O$ at the end of storage compared to the beginning. The highest h° (106.03) was in $CaCl_2.2H_2O$+REO. The highest C* (31.10) was in REO (data not presented in the table). Gago et al. (2016) reported that postharvest $CaCl_2$+1-MCP treated fruit of 'G. Delicious' were brighter, had higher h° and C* than the control. In the 'G. Smith', all treatments had very similar values at the end of storage and there was a slight decrease in brightness in all treatments except for $CaCl_2.2H_2O$ compared to the beginning. In the 'G. Smith' cv., $CaCl_2.2H_2O$+REO had the highest h° (114.40), while $CaCl_2.2H_2O$ had the highest C* (24.48). The higher h° was obtained by Paladines et al. (2014) in *Aloe vera* gel+REO treatment, Martínez-Romero et al. (2017) in REO, and Martínez-Romero et al. (2019) in REO treatments. Singh et al. (2022) reported that REO+*Aloe vera* gel preserved the color better than the untreated ones. Tamalea et al. (2021) also stated positive effects of postharvest $CaCl_2$ application.

Sensory evaluations

Overall quality

In the 'S. Delicious' cultivar, $CaCl_2.2H_2O$ and $CaCl_2.2H_2O$+REO were of good quality (8 points) at the end of storage, followed by REO (7.66 points) and control (7 points). In the 'G. Delicious', $CaCl_2.2H_2O$+REO had the highest score (7.66 points) at the end of storage, followed by control and $CaCl_2.2H_2O$, and REO had the lowest score (4.33 points). In the 'G. Delicious', staining was observed on the fruit peel starting from the 2nd month in REO. In previous studies, there is no such finding related to this in any fruit species and cultivar in which postharvest essential oil applications were made. It is thought that the staining may be related to a reaction of the peel structure of the 'G. Delicious' apple cultivar to the treatments. At the end of storage REO had the best score in the 'G. Smith' cultivar (8.66 points), followed by $CaCl_2.2H_2O$+REO (8 points) and $CaCl_2.2H_2O$ (7.33 points). The lowest score (6.66 points) was recorded in the control (Table 10). Ullah et al. (2007) reported that $CaCl_2$ significantly preserves the sensory quality of fruit by slowing down metabolic changes.

According to Kruskal-Wallis test results, when the effects of $CaCl_2.2H_2O$, REO and $CaCl_2.2H_2O$+REO combined treatments on the overall quality of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars were evaluated according to the cultivar x month and application x month combination, the difference between the rank means of the months was statistically significant ($P<0.05$) (Table 11).

Taste and aroma

At the end of storage in the 'S. Delicious' cultivar, the taste and aroma of the fruit was evaluated as good with 4 points in $CaCl_2.2H_2O$, $CaCl_2.2H_2O$+REO and control group and 3.66 points in REO. The reason for the lower score of the fruit in REO may be a greasy feeling caused by the application. At the end of storage in the 'G. Delicious' cultivar, it was observed that $CaCl_2.2H_2O$+REO and REO were better (4 points) than other treatments for preserving the taste and aroma of fruit. While the fruit treated with $CaCl_2.2H_2O$ were evaluated as medium (3 points) by the panellists, they stated a decrease in fruit taste and perceived a slight bitterness. The control group fruit had 2.66 points in the evaluation made by the panellists. In the 'G. Smith' cultivar, the taste and aroma of the fruit treated with REO and $CaCl_2.2H_2O$+REO were

Table 12. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on the taste and aroma (points) of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars

Cultivar		Storage period (months)						
	Application	0	1	2	3	4	5	6
'S. Delicous'	$CaCl_2.2H_2O$**	5.00	5.00	5.00	4.66	4.66	4.33	4.00
	REO***	5.00	5.00	4.66	4.66	4.66	4.33	4.00
	$CaCl_2.2H_2O$+REO	5.00	5.00	5.00	5.00	4.66	4.33	4.00
	Control	5.00	5.00	5.00	4.33	4.33	4.00	3.66
'G. Delicous'	$CaCl_2.2H_2O$	5.00	5.00	5.00	5.00	4.33	4.00	3.00
	REO	5.00	4.33	4.66	4.00	4.00	4.00	4.00
	$CaCl_2.2H_2O$+REO	5.00	5.00	5.00	4.66	4.00	4.33	4.00
	Control	5.00	5.00	5.00	5.00	4.33	4.00	2.66
'G. Smith'	$CaCl_2.2H_2O$	5.00	5.00	5.00	5.00	4.33	4.00	4.33
	REO	5.00	5.00	5.00	5.00	5.00	4.00	5.00
	$CaCl_2.2H_2O$+REO	5.00	5.00	5.00	5.00	5.00	4.00	5.00
	Control	5.00	5.00	4.66	5.00	4.33	4.33	3.66

**$CaCl_2.2H_2O$: Calcium chloride dihydrate, ***REO: Rosehip essential oil evaluated as very good, and these treatments had the highest score (5 points) at the end of storage. At the end of storage, $CaCl_2.2H_2O$ (4.33 points) also positively affected on the preservation of the taste and aroma of the fruit, while the fruit in the control group had a lower score (3.66 points) compared to the other treatments. According to the taste and aroma evaluations of the fruit, the fruit was of edible quality at the end of storage in all cultivars and all treatments. REO and $CaCl_2.2H_2O$+REO were slightly more prominent than the other treatments in terms of taste and aroma in all cultivars (Table 12). The findings obtained in this study are consistent with the literature (Paladines et al., 2014; Gemeda et al., 2021; Tamalea et al., 2021; Singh et al., 2022).

According to Kruskal-Wallis test results, when the effects of $CaCl_2.2H_2O$, REO and $CaCl_2.2H_2O$+REO combined treatments on the taste and aroma of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars were evaluated according to the cultivar x month and application x month combination, the difference between the rank means of the months was statistically significant (P<0.05) (Table 13).

Table 13. Effects of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on the taste and aroma (points) of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars according to cultivar x month and application x month combination according to Kruskal-Wallis test results

Cultivar	By cultivar x month combination							
	Storage period (months)							
	Application	**0**	**1**	**2**	**3**	**4**	**5**	**6**
'S. Delicous'	$CaCl_2.2H_2O$[**]	14.50	14.50	14.50	11.00	11.00	7.50	4.00
	REO[***]	15.00	15.00	11.67	11.67	11.67	8.33	3.67
	$CaCl_2.2H_2O$+REO	14.00	14.00	14.00	14.00	10.50	7.00	3.50
	Control	16A[*]	16A	16A	9B	9B	5.5B	5.5B
'G. Delicous'	$CaCl_2.2H_2O$	15A	15A	15A	15A	8.33B	5B	3.66B
	REO	18.5A	12.5AB	15.5A	9.5B	7B	7B	7B
	$CaCl_2.2H_2O$+REO	15.5A	15.5A	15.5A	12AB	5C	8.5BC	5C
	Control	15A	15A	15A	15A	8.33B	5B	3.66B
'G. Smith'	$CaCl_2.2H_2O$	14.5A	14.5A	14.5A	14.5A	7.5A	4B	7.5A
	REO	12.5A	12.5A	12.5A	12.5A	12.5A	2B	12.5A
	$CaCl_2.2H_2O$+REO	12.5A	12.5A	12.5A	12.5A	12.5A	2B	12.5A
	Control	15.00	15.00	11.67	15.00	8.33	8.33	3.67
Cultivar	**By application x month combination**							
	Storage period (months)							
	Application	**0**	**1**	**2**	**3**	**4**	**5**	**6**
'S. Delicous'	$CaCl_2.2H_2O$[**]	5.00	5.00	5.00	4.00	6.00	6.00	5.00
	REO[***]	5.00	6.00	4.50	5.50	5.67	6.33	3.5B
	$CaCl_2.2H_2O$+REO	5.00	5.00	5.00	5.50	5.50	5.50	3.50
	Control	5.00	5.00	5.50	3.00	5.00	4.50	6.00
'G. Delicous'	$CaCl_2.2H_2O$	5.00	5.00	5.00	5.50	4.50	4.50	3.67
	REO	5.00	3.00	4.50	2.50	2.33	3.67	3.5B
	$CaCl_2.2H_2O$+REO	5.00	5.00	5.00	4.00	2.50	5.50	3.50
	Control	5.00	5.00	5.50	6.00	5.00	4.50	4.50
'G. Smith'	$CaCl_2.2H_2O$	5.00	5.00	5.00	5.50	4.50	4.50	6.33
	REO	5.00	6.00	6.00	7.00	7.00	5.00	8A
	$CaCl_2.2H_2O$+REO	5.00	5.00	5.00	5.50	7.00	4.00	8.00
	Control	5.00	5.00	4.00	6.00	5.00	6.00	4.50

[*]According to the Kruskal-Wallis test, capital letters indicate differences between cultivars in each cultivar x month and application x month combination.
[**]$CaCl_2.2H_2O$: Calcium chloride dihydrate,[***] REO: Rosehip essential oil

Table 14. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on the odor (points) of fruit during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars

Cultivar	Application	Storage period (months) 0	1	2	3	4	5	6
'S. Delicous'	$CaCl_2.2H_2O$**	0	0	0	0	0	0	0
	REO***	0.66	0.66	0	0.66	0	0	0.33
	$CaCl_2.2H_2O$+REO	0	0	0	0	0	0	0
	Control	0	0	0	0	0	0	0.33
'G. Delicous'	$CaCl_2.2H_2O$	0	0	0	0	0	0	0
	REO	0	0.66	0	0.33	0.66	0.33	0.33
	$CaCl_2.2H_2O$+REO	0	0	0	0	0.33	0	0.33
	Control	0	0	0	0	0.33	0	0
'G. Smith'	$CaCl_2.2H_2O$	0	0	0	0	0	0.33	0.33
	REO	0	0.33	0	0	0	0	0.33
	$CaCl_2.2H_2O$+REO	0	0	0	0	0	0.33	0.33
	Control	0	0	0.33	0	0	0	0

$CaCl_2.2H_2O$: Calcium chloride dihydrate, * REO: Rosehip essential oil

Table 15. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on the percentage of decay (%) during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars

Cultivar	Application	Storage period (months) 0	1	2	3	4	5	6
'S. Delicous'	$CaCl_2.2H_2O$**	0^{ns}	0	0	0	0	0	0
	REO***	0	0	0	0	0	3	0
	$CaCl_2.2H_2O$+REO	0	0	0	0	0	0	0
	Control	0	0	0	0	0	3	3
'G. Delicous'	$CaCl_2.2H_2O$	0	0	0	0	0	10	0
	REO	0	0	0	0	8	28	0.33
	$CaCl_2.2H_2O$+REO	0	0	0	0	0	0	0.33
	Control	0	0	0	0	2	26	0
'G. Smith'	$CaCl_2.2H_2O$	0	0	0	0	0	7	10
	REO	0	0	0	0	0	0	0
	$CaCl_2.2H_2O$+REO	0	0	0	0	1	1	0
	Control	0	0	0	0	0	2	5

nsNot significant, **$CaCl_2.2H_2O$: Calcium chloride dihydrate,*** REO: Rosehip essential oil

Odor

In this study, 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars were also evaluated for any bad odor other than fruity odor during storage. According to the evaluations made by the panellists, although a slightly different odor was perceived during storage in the REO in general and at the end of storage in the $CaCl_2.2H_2O$+REO in the 'G. Delicious', in the $CaCl_2.2H_2O$ and $CaCl_2.2H_2O$+REO in the 'G. Smith', it was not at a level that would affect the fruit taste, as can be seen in Table 14, where taste and aroma values are given. The findings obtained in this study are consistent with the findings of Paladines et al. (2014), Gemeda et al. (2021), Tamalea et al. (2021) and Singh et al. (2022).

According to the Kruskal-Wallis test results, when the effects of $CaCl_2.2H_2O$, REO and $CaCl_2.2H_2O$+REO treatments on fruit odor during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars were evaluated according to the cultivar x month and application x month combination, the difference between the rank mean of months was not statistically significant (P<0.05).

Decay

Table 15 shows that no rot was detected in any cultivar and treatment until the 4th month of storage. While no decay was detected in the 'S. Delicious' cultivar in the 4th month of storage, 8% decay was detected in the REO and 2% in the control group in the 'G. Delicious' cultivar; 1% decay was detected in the $CaCl_2.2H_2O$+REO in 'G. Smith' cultivar. At the end of the storage period, no decay was detected in 'S. Delicious' cultivar in treatments other than control, in 'G. Delicious' cultivar in $CaCl_2.2H_2O$ and the 'G. Smith' cultivar in REO and $CaCl_2.2H_2O$+REO, while the highest decay was in the control group of the 'G. Delicious' cultivar with 40%. As can be seen from the data obtained, the effect of treatments on the decay rate of apple cultivars was variable. It was observed that all treatments significantly reduced the fruit decay rate in 'S. Delicious' cultivar; $CaCl_2.2H_2O$ and $CaCl_2.2H_2O$+REO in 'G. Delicious' cultivar, and REO and $CaCl_2.2H_2O$+REO in 'G. Smith' cultivar compared to the control group.

Salem and Moussa (2014) reported that $CaCl_2$ treatment protected the apple cv. of the 'Anna' against various rotting agents during storage. Sohail et al. (2015) reported that postharvest application of $CaCl_2$ reduced the decay rate in peach fruit. Eric et al. (2015) reported that postharvest application of $CaCl_2$ reduced the decay rate in tomato fruit. Gago et al. (2016) reported the decay rate in the 'G. Delicious' cultivar was significantly reduced in $CaCl_2$ application compared to the control group. El-Dengawy et al. (2018) reported that postharvest $CaCl_2$ immersion of guava fruit stored under room conditions reduced the percentage of fruit decay. Similar to our findings, Rabiei et al. (2011) reported that thyme and lavender essential oils significantly reduced the decay rates of apple cv. of the 'Jonagold'. Mahmoud et al. (2019) reported that essential oil treatment had positive effects against decay agents in the 'Anna' apple cultivar. Gemeda et al. (2021) reported that calcium immersion treatments increase the likelihood that fruit is less susceptible to rot during storage, and the researcher related the higher decay rate in untreated fruit to the result of lower tissue strength and cellular disorganization.

According to the Kruskal-Wallis test results, when the effects of $CaCl_2.2H_2O$, REO and $CaCl_2.2H_2O$+REO on the percentage of fruit decay during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars were evaluated according to the cultivar x month and application x month combination, the difference between the rank mean of months was not statistically significant ($P<0.05$).

Superficial scald (SS) and superficial scald severity (SSS)

SS is one of the most common postharvest physiological disorders of some apple cultivars, although its development's aetiology and biochemistry are not yet fully understood. SS involves the synthesis of (E,E)-alpha-farnesene, a sesquiterpene, and the primary products of its oxidation, namely the accumulation of conjugated trienols in the fruit epidermis and hypodermis. This causes the rupture of cell membranes, leading to polyphenoloxidase-mediated browning of the fruit peel (Gago et al., 2016). Typical symptoms of SS are brown or black spots on the fruit peel during storage (Zanella and Rossi, 2015). In this study, except for the 'G. Smith' apple cultivar, no symptoms of SS were observed in other cultivars. In the 'G. Smith' apple cultivar, no SS was observed in any treatment until the 6th month of storage. At the end of the storage period, SS was detected in the control group and $CaCl_2.2H_2O$ treated fruit. In the $CaCl_2.2H_2O$-treated fruit, SS was recorded as 3%, while 7% SS was detected in the control group. In the fruit treated with $CaCl_2.2H_2O$, SSS was evaluated as 0.25%, while in the control group SSS was higher (1%) (Table 16).

Shatat and Fadhil (2010) reported that postharvest $CaCl_2$ application effectively reduced SS during storage in the 'G. Smith' apple cultivar. Gago et al. (2016) reported that

Table 16. Effect of postharvest $CaCl_2.2H_2O$, REO, and $CaCl_2.2H_2O$+REO applications on superficial scald (%) and superficial scald severity (%) of fruit during storage in 'G. Smith' apple cultivar

Cultivar	Application	Superficial scald Storage period (months)						
		0	1	2	3	4	5	6
'G. Smith'	$CaCl_2.2H_2O$**	0ns	0	0	0	0	0	3
	REO***	0	0	0	0	0	0	0
	$CaCl_2.2H_2O$+REO	0	0	0	0	0	0	0
	Control	0	0	0	0	0	0	7
		Superficial scald severity Storage period (months)						
	$CaCl_2.2H_2O$**	0ns	0	0	0	0	0	0.25
	REO***	0	0	0	0	0	0	0
	$CaCl_2.2H_2O$+REO	0	0	0	0	0	0	0
	Control	0	0	0	0	0	0	1

nsNot significant, **$CaCl_2.2H_2O$: Calcium chloride dihydrate,*** REO: Rosehip essential oil

$CaCl_2$ effectively reduced SS during storage in apple fruit compared to the control group. According to the findings obtained, REO and $CaCl_2.2H_2O$+REO were successful in preventing the occurrence of SS in fruit. Based on the fact that an oxidation mechanism is effective in the emergence of SS (Gago et al., 2016) and that the emergence of SS is also prevented in environments where oxygen is reduced (Poirier et al., 2020). It is thought that the emergence of SS in fruit treated with REO and $CaCl_2.2H_2O$+REO was prevented in this study because REO forms a barrier and modified atmosphere in the fruit peel. Indeed, respiration rate (Table 5) and ethylene production (Table 6) support this finding.

CONCLUSION

As a result, when all the data were evaluated together, it was revealed that the postharvest edible coating applications in the form of $CaCl_2.2H_2O$, REO and $CaCl_2.2H_2O$+REO combination had positive contributions to the storage life of the fruit and on the parameters constituting the fruit quality during storage in 'S. Delicious', 'G. Delicious' and 'G. Smith' apple cultivars. However, it was observed that the effects on some quality characteristics differed according to the cultivars. In the 'S. Delicious', REO was slightly more prominent than the other treatments, but the other treatments were also effective in preserving fruit quality compared to the control group. In the 'G. Delicious', REO was prominent in preserving fruit quality characteristics. However, REO can be recommended for short-term storage since the formation of spots on the fruit peel starting from the 2^{nd} month will negatively affect the market value. For this cultivar, other treatments were effective in preserving fruit quality compared to the control group. In the 'G. Smith', $CaCl_2.2H_2O$ and REO applications had a more positive contribution to the quality characteristics of the fruit than $CaCl_2.2H_2O$+REO. However, REO and $CaCl_2.2H_2O$+REO were more successful in preventing the emergence of SS, which is an important problem for the 'G. Smith' apple cultivar. The study results recommend the use of $CaCl_2.2H_2O$ for the 'S. Delicious' apple cultivar, $CaCl_2.2H_2O$+REO for the 'G. Delicious', and REO for the 'G. Smith' cultivar.

It is thought that the results obtained will contribute to the prevention of losses that may occur in the fruit of 'G. Delicious', 'S. Delicious' and 'G. Smith' apple cultivars during storage and encourages using of alternative natural practices that can replace chemical substances that negatively affect on human health and the environment in apple storage.

COMPLIANCE WITH ETHICAL STANDARDS

Peer-review

Externally peer-reviewed.

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

This manuscript was produced from the master dissertation entitled 'Effect of post-harvest rosehip essential oil and calcium chloride application on storage time and fruit quality in some apple cultivars' prepared by Emine YİĞİT at the Institute of Graduate Education, Isparta University of Applied Sciences under the supervision of Assist Prof. Dr. Tuba DİLMAÇÜNAL. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original.

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