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Optimization of Apple (*Malus domestica* Borkh.) Shelf-life by Calcium Chloride and *Aloe vera* Gel Using Response Surface Methodology (RSM)

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ABSTRACT

Using organic and inorganic substances is a healthy and affordable way to enhance fruit quality during storage. Apple is a popular fruit with high nutritional value and mainly experiences prolonged storage periods. The present study was conducted to optimize the shelf-life of apple fruits (*Malus domestica* Borkh. 'Golden Delicious') by *Aloe vera* gel and calcium chloride ($CaCl_2$) and to evaluate apple characteristics after 90 days of cold storage. Using response surface methodology (RSM), measurements were aimed at fruit weight loss, pH, total soluble solids (TSS), total sugar (TS), fruit firmness, and juice content. As evidenced from RSM analysis, optimal conditions for apple shelf-life were achieved by 5.9% $CaCl_2$ and 33.6% *Aloe vera* gel, which reduced weight loss and maintained fruit firmness, pH, total soluble solids, total sugars, and juice content. *Aloe vera* gel and $CaCl_2$ showed similar modes of action in each case of the measured traits, except for TSS where the *Aloe vera* gel increased apple TSS, whereas $CaCl_2$ decreased it. Therefore, an optimized combination of *Aloe vera* gel and $CaCl_2$ offered a promising approach to the maintenance of apple quality in storage.

Introduction

Apple (*Malus domestica* Borkh.) is one of the most important fruit species in temperate regions and is grown commercially in different parts of the world (Prasad et al., 2021). Apples are prevalent among fruit growers due to their excellent nutritional value, high storage capacity, and suitability for fresh consumption (Lemmens et al., 2020). An apple fruit usually contains sugar (11%), fat (0.4%), protein (0.3%), carbohydrates (14.9%), vitamins, and minerals (Khan et al., 2020). Apples are usually stored for long durations at low temperatures. The quality and nutritional value of the fruits decrease during storage, and several factors affect the shelf-life of apple fruits, such as growth time, harvesting operations, and storage conditions (Korićanac et al., 2020). Decreased fruit quality is often caused

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by relatively high metabolic activities during storage (Ranjbar et al., 2018; Nybom et al., 2020). Therefore, it is essential for economic and health reasons to use techniques that improve the quality of stored apple fruits.

Calcium (Ca^{2+}) is a crucial mineral in cell walls and cellular membranes. It can maintain fruit quality and firmness while increasing fruit shelf-life (Barzegar et al., 2018; Amiri et al., 2021; Habibi et al., 2023). Ca^{2+} can delay fruit ripening and prevent a fast decline in the nutritional status of the fruit while reducing its susceptibility to diseases associated with postharvest decay (Xiong et al., 2021). Ca^{2+} can improve antioxidant capacity by scavenging free radicals imposed by biotic stressors like pathogens (García-Martí et al., 2019). The positive impact of applying Ca^{2+} on fruits is notable in postharvest management. However, excessive Ca^{2+} concentrations can cause adverse effects on fruit quality, such as loss of taste (Barzegar et al., 2018). Meanwhile, there is a growing interest in plant-based materials to improve fruit quality in postharvest management. *Aloe vera* gel is a natural, eco-friendly, plant-based edible coating. It is a pulp-based gelatinous matrix extracted from the leaf tissues of *Aloe vera* plants. *Aloe vera* gel coating reportedly mitigated browning and preserved fruit quality by inhibiting phenolic oxidation, peroxidase, and polyphenol oxidase activity (Ali et al., 2019). It is a common practice to use *Aloe vera* gel as a natural, inexpensive, edible coating that can improve fruit quality and shelf life (Habibi et al., 2022). In previous research, *Aloe vera* gel and Ca^{2+} effectively enhanced fruit quality and increased the period of apple availability for consumer consumption. The beneficial role of *Aloe vera* gel in maintaining postharvest quality has been reported in various fruits like strawberries (Sogvar et al., 2016; Amiri et al., 2021), litchi (Ali et al., 2019), green chilies (Ul Hasan et al., 2021), 'Gola' Guava (Rehman et al., 2020), and sapodilla (Khaliq et al., 2019). Other studies confirmed the beneficial effects of Ca^{2+} on fruit storage in papaya (Gao et al., 2020), *Ziziphus mauritiana* Lamk. (Jain et al., 2019), and apple (Ranjbar et al., 2018). However, there is an absence of information on the effects of combining *Aloe vera* gel and Ca^{2+} on the postharvest quality of apple fruits. Therefore, the present study aimed to evaluate how *Aloe vera* gel and Ca^{2+} affect apple fruits during storage using response surface methodology (RSM).

Materials and Methods

Apple fruits were randomly harvested from apple trees (*Malus domestica* Borkh. 'Golden Delicious') at full maturity when the fruits had grown into a desirable color and firmness. The trees were located in an orchard in Maragheh, East Azerbaijan province, Iran (37° 40' N and 46° 41' E) in October 2020. The fruits were free from disease and mechanical injuries. They were uniform in size, shape, and color. After the harvest, they were immediately taken to a laboratory for different treatments.

Three-year-old *Aloe vera* plants were selected from a commercial greenhouse. The leaves were washed with tap water to remove dirt and were dipped in 0.1% sodium hypochlorite for 3 min. After drying, the leaves were manually peeled with a stainless steel knife. The resulting mucilaginous gel was collected and mixed in a blender. After blending, the resultant gel was filtered with a sterile muslin cloth to remove any fibrous fraction. Raw gel pH was adjusted to 3.75 (Navarro et al., 2011) with citric acid, pasteurized at 65 °C for 30 min (Vieira et al., 2016), and cooled for further use. The gel solution was diluted with distilled water at a 1:1 (v/v) ratio, and glycerol (1%) was added as a plasticizer. Calcium chloride ($CaCl_2$, Sigma-Aldrich, US) was purchased as a powder from Petrokimia Company (Iran). $CaCl_2$ treatments were 1, 3, 5, 7, and 9%, so relevant amounts of $CaCl_2$ were precisely weighed and dissolved in distilled water. The fruits were immersed in the solutions for 5 min. After the treatments, the fruits were stored in cold storage (2 °C) for 90 days, and apple quality traits were measured thereafter.

Weight loss was calculated according to the following formula:

$$Fruit\ weight\ loss\ (\%) = [\frac{(initial\ weight - final\ weight)}{initial\ weight}] \times 100$$

Fruit firmness was measured on both sides of each fruit with a penetrometer (Effegi, Florence, Italy) fitted with an 11 mm diameter probe (Ranjbar et al., 2018). The fruit pH was determined by a pH meter when sampling the fruits. The TSS was measured using a digital hand refractometer (PAL, Atago, Tokyo, Japan) at room temperature and was expressed as Brix value (Ali et al., 2011). The total and reduced sugar contents in fruits were determined by a relevant method in the available literature (Chandraju et al., 2013).

Response surface methodology (RSM) was applied to optimize *Aloe vera* and $CaCl_2$ doses on the shelf-life of apple fruits. Data analysis and model construction were carried out using Design-Expert software (version 6.0.8, Stat-Ease Inc., Minneapolis, MN). The Central Composite

Rotatable Design (CCRD) with a quadratic model was employed. Each independent variable had 5 levels, pertaining to *Aloe vera* gel and calcium chloride treatments. Six replicates of the central point were chosen in random order according to a CCRD configuration for three factors divided in three blocks. The α-values in the design outside the ranges were selected for rotatability of the design (Thompson et al., 1982). The central points for these designs were selected with the treatments at levels expected to yield satisfactory experimental results. The response functions were weight loss, fruit firmness, pH, total soluble solids, total sugars, and fruit juice. The response variable values are related to the coded variables by a second degree polynomial. Two treatment groups, each at 5 levels, were applied in three replicates. The $CaCl_2$ concentration at 3-9% and *Aloe vera* gel at 10-50% were independent variables that were applied to affect fruit weight loss, fruit firmness, pH, total soluble solids (TSS), total sugar, and juice content.

Results

Fruit weight loss

Fruit weight loss was significantly affected by the interaction of $CaCl_2$ and *Aloe vera* gel (Table 1). By the application of $CaCl_2$ and *Aloe vera* gel, fruit weight was better maintained during storage, compared to the control. The *Aloe vera* gel showed a significant ability to prevent fruit weight loss (at 30% concentration) and exhibited maximal efficiency slightly beyond the 40% concentration ($P \leq 0.01$) (Fig. 1a). The preventive effect of $CaCl_2$ on fruit weight loss occurred significantly by applying $CaCl_2$ concentrations higher than 5%, peaking at 7.07% that reduced the weight loss (2.1%) significantly ($P \leq 0.01$) (Fig. 1b). Optimal concentrations of $CaCl_2$ and *Aloe vera* gel were 7.07 and 43.08%, respectively. According to Figure 1, the trends of changes in fruit weight loss that occurred in response to $CaCl_2$ and *Aloe vera* gel applications were almost similar. Based on R^2 and standard deviation, the predicted model confirmed the adequacy and accuracy of the tests (Equation 1).

Equation 1.

$$Weight\ loss = 3.7092 - 0.2080\ CaCl^2 - 0.0468\ Aloe\ vera\ gel + 0.0007\ CaCl^2 \times Aloe\ vera\ gel + 0.0131 \times (CaCl^2)^2 + 0.0004 \times (Aloe\ vera\ gel)^2$$

Table 1. ANOVA for apple fruit traits in response to *Aloe vera* gel (AVG%) and calcium chloride ($CaCl_2$%) applications.

	MS					
S.V.	Weight loss	Firmness	pH	TSS	TS	Juice
Model	0.09^{**}	0.17^{**}	0.016^{**}	0.041^{**}	0.15^{**}	2.43^{**}
$CaCl_2$ (%)	0.15^{**}	0.17^{**}	0.034^{**}	0.08^{**}	0.37^{**}	0.98^{**}
AVG (%)	0.21^{**}	0.55^{**}	0.041^{**}	0.002^{ns}	0.068^{**}	8.81^{**}
$CaCl_2$ × AVG	0.0009^{ns}	0.00^{ns}	0.0004^{**}	-	-	0.026^{**}
$(CaCl_2)^2$	0.063^{**}	0.062^{**}	0.0006^{**}	-	-	0.55^{**}
$(AVG)^2$	0.057^{**}	0.075^{**}	0.0034^{**}	-	-	2.31^{**}
Lack-of-fit	0.001^{**}	0.0006^{ns}	0.00004^{ns}	0.005^{ns}	0.0002^{**}	0.034^{**}
Error	0.00003	0.00013	0.00003^{**}	0.006^{**}	0.0006^{ns}	0.0002^{**}
CV	1.15	0.22	0.14	0.52	0.19	0.52

^{ns} non-significant, * and ** represent significance at 5 and 1 percent probability levels, respectively.

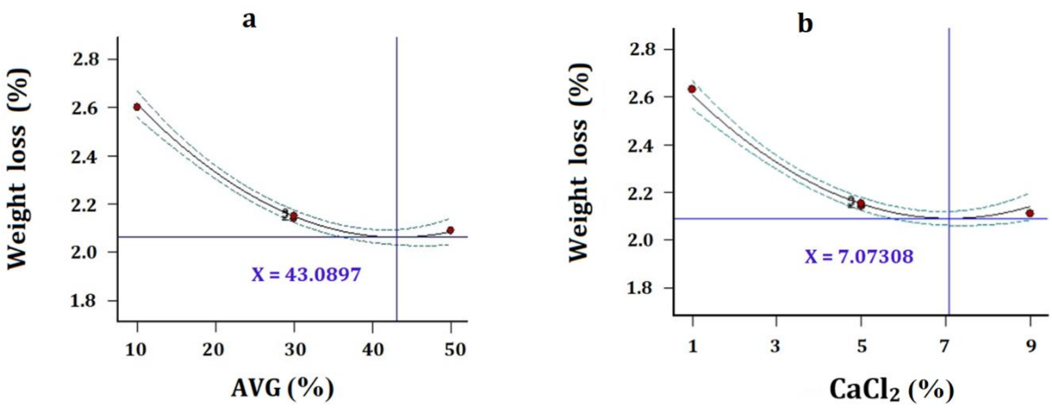

Fig. 1. Changes in fruit weight loss (%) in response to *Aloe vera* gel (AVG%) (a) and calcium chloride ($CaCl_2$%) (b) applications, showing a significant ability to control fruit weight loss in percentages.

Fruit firmness

Interactions of $CaCl_2$ and *Aloe vera* gel significantly affected fruit firmness (Table 1). By the application of $CaCl_2$ and *Aloe vera* gel, fruit firmness partly retained its original condition through storage, compared to the control. The *Aloe vera* gel showed a significant ability to prevent the loss of fruit firmness, and this was evident from the 30% *Aloe vera* gel concentration onwards. Maximum efficiency occurred at 48% *Aloe vera* gel concentration that maintained fruit firmness at 8.61 kg cm^{-2} ($P \leq 0.01$) (Fig. 2a). The supportive effect of $CaCl_2$ on maintaining fruit firmness occurred significantly by applying $CaCl_2$ concentrations higher than 5%, reaching maximum efficiency at 7.29% $CaCl_2$ that maintained fruit firmness at 8.5 kg cm^{-2} ($P \leq 0.01$) (Fig. 2b). Fruit firmness then decreased slightly when using $CaCl_2$ beyond the 7.29% concentration. Optimal concentrations of $CaCl_2$ and *Aloe vera* gel were 7.29 and 48%, respectively. According to Figure 2, the trends of changes in fruit firmness that occurred in response to $CaCl_2$ and *Aloe vera* gel applications were almost similar. Based on R^2 and standard deviation, the predicted model confirmed the adequacy and accuracy of the tests (Equation 2).

Equation 2.

$$Fruit\ firmness = 6.6428 + 0.1907\ CaCl^2 + 0.0557\ Aloe\ vera\ gel - 3.9 \times 10 - 17\ CaCl^2 \times Aloe\ vera\ gel - 0.01301 \times (CaCl^2)^2 - 0.00057 \times (Aloe\ vera\ gel)^2$$

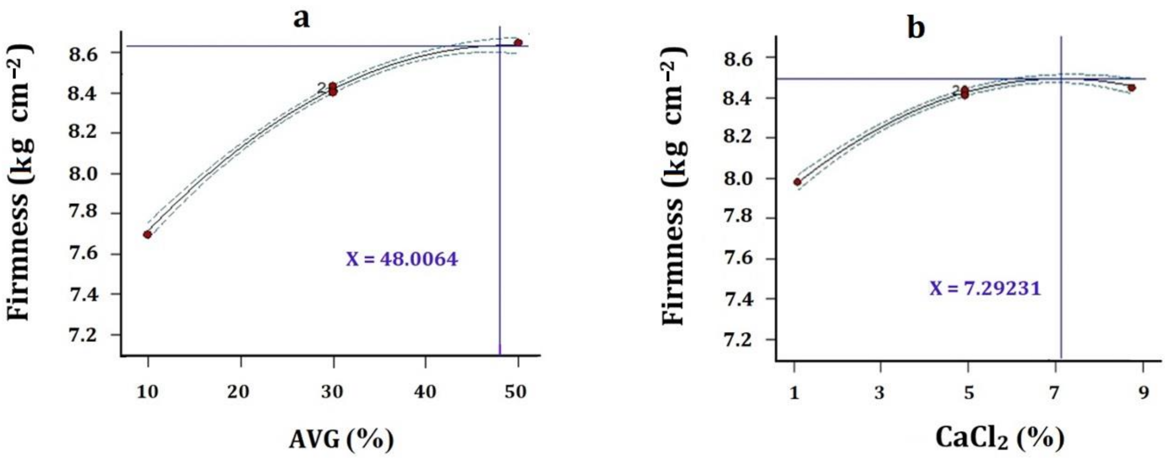

Fig. 2. Changes in fruit firmness (kg cm^{-2}) in response to *Aloe vera* gel (AVG%) (a) and calcium chloride ($CaCl_2$%) (b) applications, showing a significant ability to maintain fruit firmness.

Fruit pH

Changes in fruit pH were observed during the storage period. Maintenance of fruit pH occurred in response to $CaCl_2$ and *Aloe vera* gel applications (Table 1), whereby the fruit pH did not increase markedly in storage, compared to the control. The *Aloe vera* gel showed a significant ability to prevent pH increase and exhibited maximal efficiency at 50% concentration ($P \leq 0.01$), causing a significant maintenance of the pH level (4.18) during storage (Fig. 3a). The preventive effect of $CaCl_2$ on the increase in pH occurred significantly by applying concentrations higher than 5%, peaking at 9% that maintained fruit pH (4.13) significantly (Fig. 3b). Optimal concentrations of $CaCl_2$ and *Aloe vera* gel were 9 and 50%, respectively. According to Figure 3, the trends of changes in fruit pH that occurred in response to $CaCl_2$ and *Aloe vera* gel applications were almost similar. According to R^2 and standard deviation, the predicted model confirmed the adequacy and accuracy of the tests (Equation 3).

Equation 3.

$$pH = 4.7053 - 0.05502\ CaCl^2 - 0.01454\ Aloe\ vera\ gel + 0.0005\ CaCl^2 \times Aloe\ vera\ gel + 0.00133 \times (CaCl^2)^2 + 0.00010 \times (Aloe\ vera\ gel)^2$$

Fruit total soluble solids (TSS)

$CaCl_2$ and *Aloe vera* gel affected changes in fruit TSS differently. The results showed that $CaCl_2$ and *Aloe vera* gel functioned dissimilarly on TSS accumulation (Fig. 4). $CaCl_2$ decreased the TSS, whereas the *Aloe vera* gel caused a negligible increase in TSS. The application of *Aloe vera* gel (50%) increased the TSS slightly (14.9 Brix) during storage (Fig. 4a). $CaCl_2$ (9%) had the most significant effect on reducing the TSS (from 15.17 to 14.72 Brix) (Fig. 4b). According to Figure 4, the trends of changes in fruit TSS were dissimilar when comparing the effects of $CaCl_2$ and *Aloe vera* gel applications. According to R^2, a model could

not be predicted for the effects of $CaCl_2$ and *Aloe vera* gel on TSS (Table 1). Equation 4 describes $CaCl_2$ and *Aloe vera* gel affecting fruit TSS.
Equation 4.

$$TSS = 15.04186 - 0.04083\ CaCl^2 + 0.00133\ Aloe\ vera\ gel$$

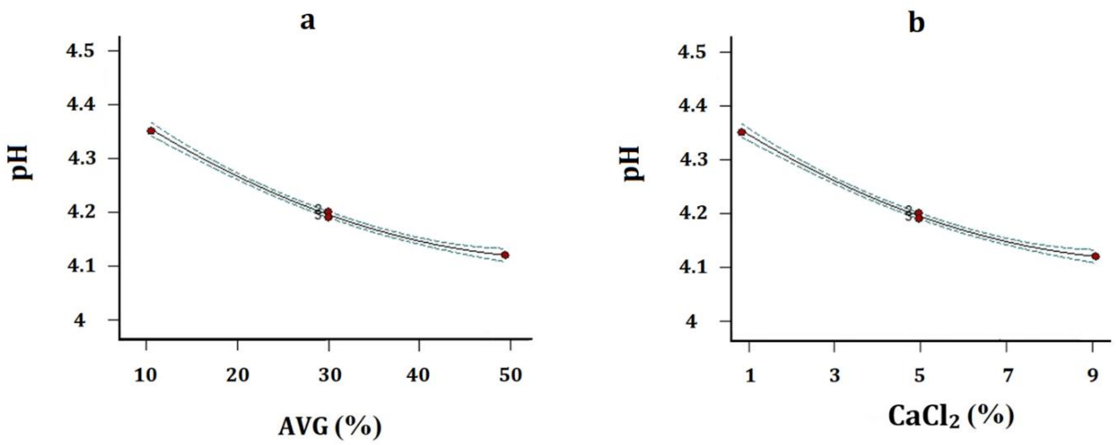

Fig. 3. Changes in fruit pH in response to *Aloe vera* gel (AVG%) (a) and calcium chloride ($CaCl_2$%) (b) applications, showing that the treatments prevented increases in fruit pH value.

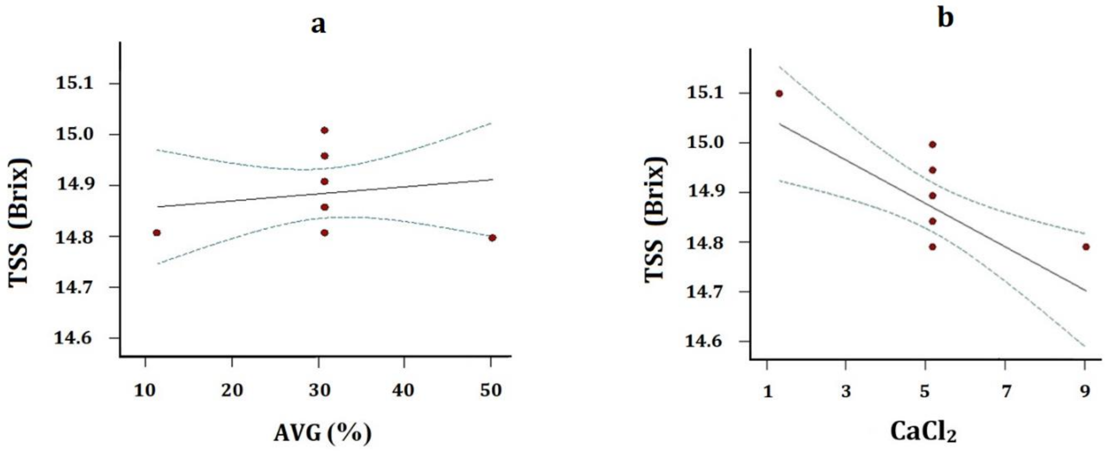

Fig. 4. Changes in fruit total soluble solids (Brix) in response to *Aloe vera* gel (AVG%) (a) and calcium chloride ($CaCl_2$%) (b) applications, showing that the *Aloe vera* gel slightly increased the total soluble solids (TSS), whereas calcium chloride ($CaCl_2$) decreased it.

Fruit total sugar (TS)

TS accumulation was significantly ($P \leq 0.01$) affected by the interaction of $CaCl_2$ and *Aloe vera* gel application (Table 1). According to RSM results, $CaCl_2$ was more effective in altering the TS, compared to the effectiveness of *Aloe vera* gel (Fig. 5). Changes in fruit TS were observed during the storage period. Maintenance of fruit TS occurred in response to $CaCl_2$ and *Aloe vera* gel applications (Table 1), whereby the fruit TS did not increase markedly in storage, compared to the control. The *Aloe vera* gel showed a significant ability to prevent TS increase and exhibited maximal efficiency at 50% concentration ($P \leq 0.01$), causing a significant maintenance of TS (11.0) during storage (Fig. 5a). The preventive effect of $CaCl_2$ on the increase in TS occurred significantly by applying concentrations higher than 5%, peaking at 9% that maintained the fruit TS (11.0) significantly (Fig. 5b). Optimal concentrations of $CaCl_2$ and *Aloe vera* gel were 9 and 50%, respectively. According to Figure 5, the trends of changes in fruit TS that occurred in response to $CaCl_2$ and *Aloe vera* gel applications were almost similar. According to R^2 and standard deviation, the predicted model confirmed the adequacy and accuracy of the tests (Equation 5).
Equation 5.

$$Total\ sugar = 11.64038\ CaCl^2 - 0.05\ Aloe\ vera\ gel + 0.00133\ Aloe\ vera\ gel$$

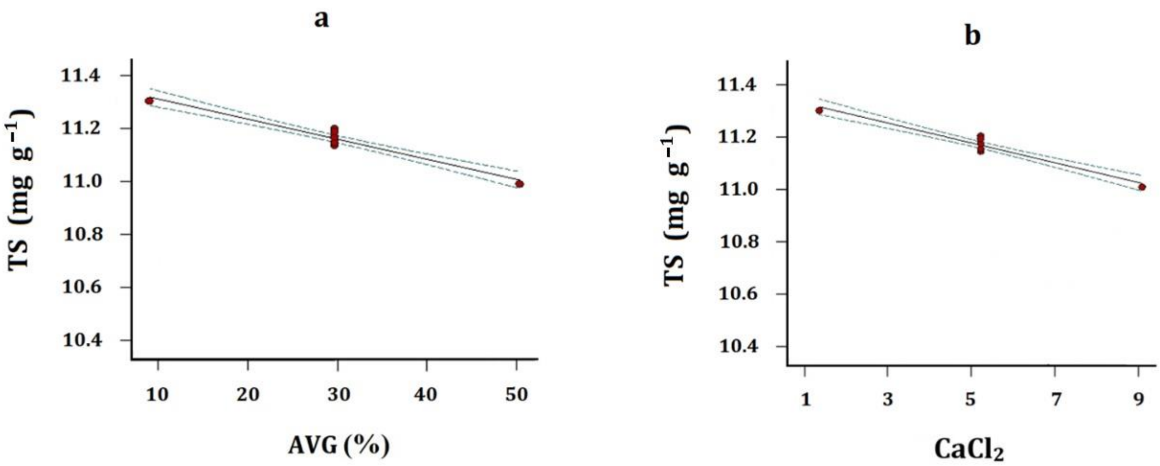

Fig. 5. Changes in total sugar content in response to *Aloe vera* gel (AVG%) (a) and calcium chloride ($CaCl_2$%) (b) applications, showing that the treatments prevented increases in the total sugar (TS) content.

Fruit juice (%)

Fruit juice content was significantly affected by the interaction of $CaCl_2$ and Aloe vera gel ($P \leq 0.01$). Juice content significantly increased in response to $CaCl_2$ and Aloe vera gel (Fig. 6). Specifically, 6.77 and 43.57% of $CaCl_2$ and Aloe vera gel, respectively, appeared to be optimal concentrations that led to maximum juice content. Interactions of $CaCl_2$ and Aloe vera gel significantly affected fruit juice content (Table 1). By the application of $CaCl_2$ and Aloe vera gel, fruit juice partly retained its original condition through storage, compared to the control. The Aloe vera gel showed a significant ability to prevent the loss of fruit juice, and this was evident from the 30% Aloe vera gel concentration onwards. Maximum efficiency occurred at 43.57% Aloe vera gel concentration that maintained the fruit juice at 24.2% ($P \leq 0.01$) (Fig. 6a). The supportive effect of CaCl2 on maintaining fruit juice content occurred significantly by applying $CaCl_2$ concentrations higher than 5%, reaching maximum efficiency at 6.77% $CaCl_2$ that maintained the fruit juice at 23.92% ($P \leq 0.01$) (Fig. 6b). According to Figure 6, the trends of changes in fruit juice that occurred in response to $CaCl_2$ and Aloe vera gel applications were almost similar. Based on R^2 and standard deviation, the predicted model confirmed the adequacy and accuracy of the tests (Equation 6).

Equation 6.

$$Juice\ content = 17.27343 + 0.40573\ CaCl^2 + 0.25614\ Aloe\ vera\ gel + 0.004\ CaCl^2 \times Aloe\ vera\ gel + 0.038739 \times (CaCl^2)^2 + 0.0031734 \times (Aloe\ vera\ gel)^2$$

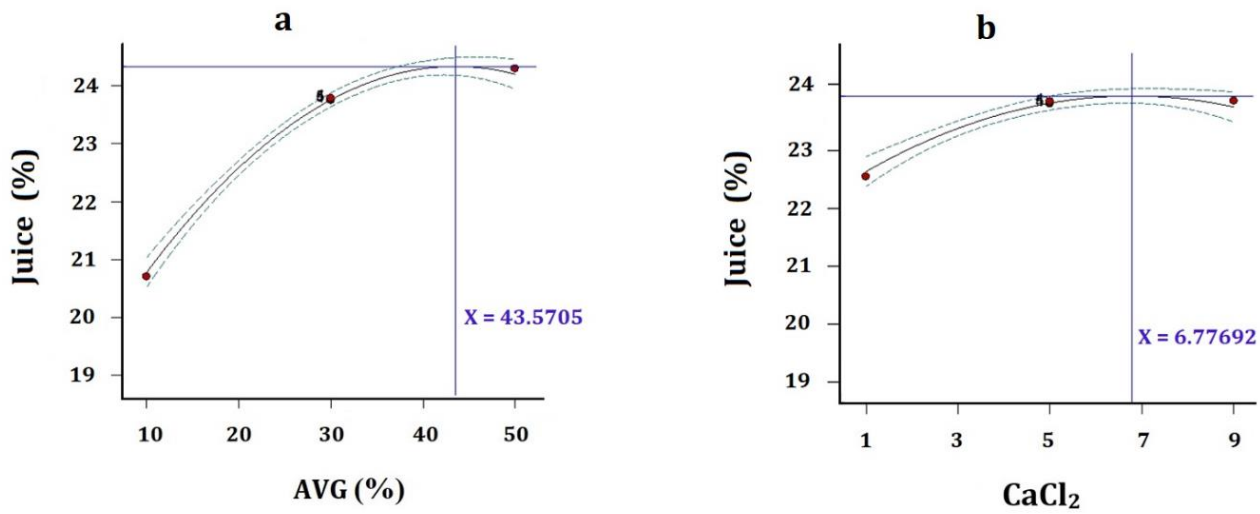

Fig. 6. Changes in fruit juice content (%) in response to *Aloe vera* gel (AVG%) (a) and calcium chloride ($CaCl_2$%) (b) applications, showing a significant ability to maintain fruit juice.

The treatment variables that led to different responses in stored apple fruits are summarized in Table 2. It is noteworthy that each trait responded differently to various treatment concentrations. Weight loss, pH, TSS, and TS were intended for minimum values, whereas fruit firmness and fruit juice content were intended for maximum values upon the application of *Aloe vera* gel and calcium chloride treatments in a dose-dependent manner.

Table 2. Ranges in variables for maintaining quality characteristics in apple fruits in response to *Aloe vera* gel (AVG%) and calcium chloride ($CaCl_2$%) applications.

Variable	Purpose	Minimum	Maximum
$CaCl_2$ (%)	Dose-dependent	1	9
AVG (%)	Dose-dependent	10	50
Weight loss (%)	Minimum value	2.05	2.6
Fruit firmness (kg cm^{-2})	Maximum value	7.75	8.65
pH	Minimum value	4.11	4.35
Total soluble solids (Brix)	Minimum value	14.72	15.1
Total sugar (mg g^{-1})	Minimum value	10.65	11.5
Juice content (%)	Maximum value	20.7	24.3

Discussion

A decrease in fruit weight can be related to metabolic activities, respiration, and transpiration (Barzegar et al., 2018; Rehman et al., 2020). Previous reports indicated various degrees of weight loss in fruits during the postharvest period (Barzegar et al., 2018). Coating apple fruits with *Aloe vera* gel created a physical barrier to moisture loss, thereby alleviating weight loss in fruits treated with *Aloe vera* gel. The RSM results indicated that *Aloe vera* gel at 43.08% optimally minimized fruit weight loss. Similar to this research, previous studies indicated doses and applications that mitigated fruit weight loss by *Aloe vera* gel on guava (Rehman et al., 2020), strawberry (Sogvar et al., 2016), and litchi (Ali et al., 2019).

$CaCl_2$ reduced weight loss in apple fruits. Since $CaCl_2$ maintained cellular membrane integrity and functionality, it led to a lower rate of moisture loss from the fruits. Ca can decrease fruit respiration rates and partly stabilize fruit weight during storage (Angeletti et al., 2010). In line with our results, Ranjbar et al. (2018) showed a significant mitigation of weight loss in apple fruits treated with calcium-based compounds.

Fruit firmness decreased during storage. However, the *Aloe vera* gel and $CaCl_2$ treatments alleviated the decrease in fruit firmness, primarily because these treatments stabilized cellular membranes and maintained their integrity (Ranjbar et al., 2018). Interactions between *Aloe vera* gel and $CaCl_2$ decreased enzymatic activities involved in fruit softening (Seyed et al., 2021). In previous research, nano-calcium treatments resulted in greater firmness values compared to calcium chloride treatments, possibly due to better absorption by plant cells. *Aloe vera* gel reportedly assisted in maintaining fruit firmness in Fagonia indica (Khaliq et al., 2019), strawberry (Sogvar et al., 2016), and papaya (Farina et al., 2020). Furthermore, $CaCl_2$ contributed to the maintenance of fruit firmness in Ziziphus mauritiana (Jain et al., 2019), papaya (Gao et al., 2021), and apple (Ranjbar et al., 2018) compared to their respective control groups.

Fruit pH increased during the storage period, but the interaction between *Aloe vera* gel and $CaCl_2$ mitigated the increase in pH value. The stability of pH under storage conditions is considered necessary for maintaining fruit quality. The increase in pH during storage results from the breakdown and decomposition of organic acids through respiratory processes (Sogvar et al., 2016). Similar to our results, Vieira et al. (2016) indicated that *Aloe vera* gel inhibited the increase of pH in blueberry juice during storage. *Aloe vera* gel and $CaCl_2$ increased the juice content in apple fruits. RSM results showed that 6.77% $CaCl_2$ and 43.8% *Aloe vera* gel were optimum treatment levels for achieving maximum juice content.

TSS decreased with $CaCl_2$ application but increased by *Aloe vera* gel. The increase in TSS during storage is usually a manifestation of polysaccharide hydrolysis and higher extract concentration. It is partly related to the decrease in fruit juice, which in turn enhances TSS. Also, respiration and aging in fruit tissues culminate in the breakdown of polysaccharides and their conversion to simpler compounds, thereby increasing TSS (Daisy et al., 2020). The TSS increased in response to *Aloe vera* gel because of starch hydrolysis into sugar compounds (Rehman et al., 2020). Previous findings reported a positive correlation between TSS and respiration rate (Khaliq et al., 2019). The decline in TSS could be due to the conversion of sugars into organic acids and a reduced respiration rate (Javed et al., 2018). Moreover, a lower TSS may cause carbohydrate hydrolysis into sugar compounds (Rehman et al., 2020). TSS and TS usually correlate with carbohydrate content. Increased levels of TSS and TS can lead to cell wall degradation. Similarly, Ranjbar et al. (2018) showed an increase in TSS and TS in apple fruits under Ca and nano-Ca applications.

Conclusion

$CaCl_2$ and *Aloe vera* gel caused improvements in the postharvest quality of apple fruits in storage. Since apple fruits are subjected to long durations of storage, finding appropriate doses of treatments that maintain fruit quality can be of prime importance from a commercial perspective. $CaCl_2$ and *Aloe vera* gel assisted in storage conditions for apple fruits and caused optimum shelf-life. Apple shelf life optimally increased by applying 5.9% $CaCl_2$ and 33.6% *Aloe vera* gel, as evidenced from RSM analysis. Thus, we can recommend these doses of $CaCl_2$ and *Aloe vera* gel as effective treatments for increasing apple shelf life during the storage time. Future research can consider the inclusion of other protective compounds that fortify the effects of $CaCl_2$ and *Aloe vera* gel on apple fruits for longer storage periods.

Conflict of Interest

The authors indicate no conflict of interest in this work.

References

Ali A, Muhammad MTM, Sijam K, Siddiqui Y. 2011. Effect of chitosan coatings on the physicochemical characteristics of Eksotika II papaya (*Carica papaya* L.) fruit during cold storage. Food Chemistry 124(2), 620-626.

Ali S, Khan AS, Nawaz A, Anjum MA, Naz S, Ejaz S, Hussain S. 2019. *Aloe vera* gel coating delays postharvest browning and maintains quality of harvested litchi fruit. Postharvest Biology and Technology 157, 110960.

Amiri S, Rezazad-Bari L, Malekzadeh S, Amiri S, Mostashari P, Ahmadi-Gheshlagh P. 2021. Effect of *Aloe vera* gel-based active coating incorporated with catechin nanoemulsion and calcium chloride on postharvest quality of fresh strawberry fruit. Journal of Food Processing and Preservation, e15960.

Angeletti P, Castagnasso H, Miceli E, Terminiello L, Concellon A, Chaves A, Vicente AR. 2010. Effect of preharvest calcium applications on postharvest quality, softening and cell wall degradation of two blueberry (*Vaccinium corymbosum*) varieties. Postharvest Biology and Technology 58(2), 98-103.

Barzegar T, Fateh M, Razavi F. 2018. Enhancement of postharvest sensory quality and antioxidant capacity of sweet pepper fruits by foliar applying calcium lactate and ascorbic acid. Scientia Horticulturae 241, 293-303.

Chandraju S, Venkatesh R, Kumar CSC. 2013. Estimation of sugars by acid hydrolysis of sorghum husk by standard methods. Journal of Chemical and Pharmaceutical Research 5(12), 1272-1275.

Daisy LL, Nduko JM, Joseph WM, Richard SM. 2020. Effect of edible gum arabic coating on the shelf-life and quality of mangoes (*Mangifera indica*) during storage. Journal of Food Science and Technology 57(1), 79-85.

Farina V, Passafiume R, Tinebra I, Scuderi D, Saletta F, Gugliuzza G, Gallotta A, Sortino G. 2020. Postharvest application of *Aloe vera* gel-based edible coating to improve the quality and storage stability of fresh-cut papaya. Journal of Food Quality 2020, 1-10.

Gao Q, Tan Q, Song Z, Chen W, Li X, Zhu X. 2020. Calcium chloride postharvest treatment delays the ripening and softening of papaya fruit. Journal of Food Processing and Preservation 44(8), e14604.

Garcia-Marti M, Pinero MC, Garcia-Sanchez F, Mestre TC, Lopez-Delacalle M, Martinez V, Rivero RM. 2019. Amelioration of the oxidative stress generated by simple or combined abiotic stress through the $K+$ and Ca^{2+} supplementation in tomato plants. Antioxidants 8(4), 81.

Habibi A, Yazdani N, Chatrabnous N, Koushesh Saba M, Vahdati K. 2022. Inhibition of browning via aqueous gel solution of *Aloe vera*: a new method for preserving fresh fruits as a case study on fresh kernels of Persian walnut. Journal of Food Science and Technology 59, 2784-2793.

Habibi A, Yazdani N, Koushesh Saba M, Chatrabnous N, Molassiotis A, Sarikhani S, Vahdati K. 2023. Natural preservation and improving lipid oxidation inhibition of fresh walnut. Horticulture, Environment, and Biotechnology 64, 133-142.

Jain V, Chawla S, Choudhary P, Jain S. 2019. Post-harvest calcium chloride treatments influence fruit firmness, cell wall components and cell wall hydrolyzing enzymes of Ber (*Ziziphus mauritiana* Lamk.) fruits during storage. Journal of Food Science and Technology 56(10), 4535-4542.

Javed MS, Randhawa MA, Ahmad Z, Sajid MW, Nasir MA, Tariq MR. 2018. Effect of CaCl2 and controlled atmosphere storage on phytochemical attributes of Guava. Food Science and Technology 38(2), 356-362.

Khaliq G, Ramzan M, Baloch AH. 2019. Effect of *Aloe vera* gel coating enriched with *Fagonia indica* plant extract on physicochemical and antioxidant activity of sapodilla fruit during postharvest storage. Food Chemistry 286, 346-353.

Khan A, Shah FN, Zeb Q, Zeeshan M, Iqbal H, Noor H. 2020. Preparation and development of fig fruit jam blended with different level of apple pulp. Biological Sciences-PJSIR 63(2), 105-112.

Korićanac A, Miletić N, Popović B, Mitrović O, Lukić M, Pešaković M., Tomić J. 2020. The effect of ULO and NA storage on changes in the quality of apple fruit (*Malus domestica* Borkh.) during shelf-life. Agronomy 10(1), 25.

Lemmens E, Alós E, Rymenants M, De Storme N, Keulemans WJ. 2020. Dynamics of ascorbic acid content in apple (*Malus x domestica*) during fruit development and storage. Plant Physiology and Biochemistry 151, 47-59.

Navarro-Verdugo AL, Goycoolea FM, Romero-Meléndez G, Higuera-Ciapara I, Argüelles-Monal W. 2011. A modified Boltzmann sigmoidal model for the phase transition of smart gels. Soft Matter 7(12), 5847-5853.

Nybom H, Ahmadi-Afzadi M, Rumpunen K, Tahir I. 2020. Review of the impact of apple fruit ripening, texture and chemical contents on genetically determined susceptibility to storage rots. Plants 9(7), 831.

Prasad H, Kumar K, Thakur DS. 2021. "Kalpa 1" a new late colour development apple (*Malus domestica* Borkh.) bud sport originated from cv. 'Starking Delicious'. Genetic Resources and Crop Evolution 68, 2273-2279.

Ranjbar S, Rahemi M, Ramezanian A. 2018. Comparison of nano-calcium and calcium chloride spray on postharvest quality and cell wall enzymes activity in apple cv. 'Red Delicious'. Scientia Horticulturae 240, 57-64.

Rehman MA, Asi MR, Hameed A, Bourquin LD. 2020. Effect of postharvest application of *Aloe vera* gel on shelf-life, activities of anti-oxidative enzymes, and quality of 'Gola' guava fruit. Foods 9(10), 1361.

Seyed RH, Rastegar S, Faramarzi S. 2021. Impact of edible coating derived from a combination of *Aloe vera* gel, chitosan and calcium chloride on maintain the quality of mango fruit at ambient temperature. Journal of Food Measurement and Characterization 15(4), 1-11.

Sogvar OB, Saba MK, Emamifar A. 2016. *Aloe vera* and ascorbic acid coatings maintain postharvest quality and reduce microbial load of strawberry fruit. Postharvest Biology and Technology 114, 29-35.

Thompson JF, Warsi ZU, Mastin CW. 1982. Boundary-fitted coordinate systems for numerical solution of partial differential equations—a review. Journal of Computational Physics 47(1), 100-108.

Ul Hasan M, Ullah Malik A, Anwar R, Sattar Khan A, Haider MW, Riaz R, Ali S, Ur Rehman RN, Ziaf K. 2021. Postharvest *Aloe vera* gel coating application maintains the quality of harvested green chilies during cold storage. Journal of Food Biochemistry 45(4), e13682.

Vieira JM, Flores-López ML, de Rodríguez DJ, Sousa MC, Vicente AA, Martins JT. 2016. Effect of chitosan-*Aloe vera* coating on postharvest quality of blueberry (*Vaccinium corymbosum*) fruit. Postharvest Biology and Technology 116, 88-97.

Xiong T, Tan Q, Li S, Mazars C, Galaud JP, Zhu X. 2021. Interactions between calcium and ABA signaling pathways in the regulation of fruit ripening. Journal of Plant Physiology 256, 153309.