Erwerbs-Obstbau (2023) 65:607–619
https://doi.org/10.1007/s10341-022-00717-3

ORIGINAL ARTICLE / ORIGINALBEITRAG

Preharvest Foliar Spray of Various Potassium Sources and Calcium Chloride Affect Fruit Color, Storability, and Bruise Susceptibility of Apples (*Malus* × *domestica* Borkh. cv. "Red Delicious")

Sahar Solhjoo[1] · **Ali Gharaghani**[1] · **Mansoureh Nazari**[2]

Received: 23 February 2022 / Accepted: 4 July 2022 / Published online: 20 July 2022

Abstract
This study was conducted in two consecutive growing seasons to evaluate the effect of pre-harvest sprays of three potassium (K) sources (KNO_3, K_2SO_4, and KCl) and calcium chloride ($CaCl_2$) on the color attributes and changes in fruit quality and bruise susceptibility of "Red Delicious" apples during 4 months of storage. During each season, the trees were sprayed five times with $CaCl_2$ ($5\,g.l^{-1}$) and three times with K sources ($2.5\,g \times l^{-1}$). Fruit qualitative traits were measured at harvest time as well as 2 and 4 months after storage at 0 °C. Results showed that all treatments positively affected the red skin color, except $CaCl_2$. During the storage period, $KNO_3 + CaCl_2$ treatment significantly increased fruit firmness (FF), total acidity (TA), and decreased water loss compared to the untreated trees, while single treatments of K sources increased titratable acidity (TA) only at harvest time. Total soluble solids (TSS) were increased by spraying trees with $KNO_3 + CaCl_2$ only at harvest time. Results also revealed that "Red Delicious" apples are more susceptible to bruise damage immediately after harvest compared to after 2 and 4 months of storage. In general, simultaneous foliar application of KNO_3 and $CaCl_2$ effectively improved the fruit quality and storability of the "Red Delicious" apple.

Keywords Fruit quality · Mechanical damage · Storage duration · Foliar nutrition · Firmness

Introduction

The fruit status at harvest is critical to its performance throughout postharvest storage. This comprises an appropriate maturity stage as well as several other factors including nutritional state and tolerance to specific storage diseases (Khan and Ali 2018). A longer shelf life allows for more seasonality, less food waste, and a better possibility of conserving fruit freshness. Weight loss, inferior appearance, softened texture, poor flavor/aroma, and decay are among the important factors limiting the storability and shelf life of apple cultivars (Piestrzeniewicz and Tomala 2000; Ashoori et al. 2013).

Additionally, bruising that occurs along the process of handling can have great economic repercussions, mainly due to the negative changes in appearance, organoleptic attributes, and fruit quality (Van Zeebroeck et al. 2007). To reduce the incidence of fruit damage, knowledge of fruit sensitivity to bruising is of interest to both growers and operators of postharvest handling and marketing facilities (Ericsson and Tahir 1996). Bruising varies among varieties (Gharaghani and Shahkoomahally 2018) and even for the same cultivar, fruit might be more susceptible to bruising under some cultivation practices (i.e., nutrition and irrigation) as well as harvest and postharvest handling conditions (Garcia et al. 1995). Also, bruising may be intensified by some other factors such as fruit water content, temperature, fruit size, and fruit firmness (FF; Jafari and Nassiri 2013; Gharaghani and Shahkoomahally 2018).

Poor skin coloration and low storability of red apples (such as "Red Delicious") are also two important concerns

Data availability All necessary data are presented in the manuscript, but the raw data will be available upon request of the reviewers or editor.

Supplementary data All necessary data are presented in the manuscript and there are no supplementary data to be included.

✉ Ali Gharaghani
agharghani@shirazu.ac.ir

[1] Department of Horticultural Sciences, College of Agriculture, Shiraz University, Shiraz, Iran

[2] Department of Horticultural Sciences, College of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran

that prevail in many orchards with warm and dry weather during the summer. In these areas, efforts such as delaying the harvest to improve red color have been unsuccessful because this negatively affects storability and quality attributes such as fruit firmness and flavor (Iglesias et al. 2002). Preharvest spraying with particular compounds/chemicals has been a widely utilized technique across the world to reduce these difficulties and limitations during postharvest storage and handling (Lara 2013). Fruit quality characteristics are substantially influenced by the orchard nutritional practices. Calcium (Ca) and potassium (K) are among the most important nutrient elements that clearly affect the quality of tree fruits (Nava et al. 2008; Ashoori et al. 2013). Moreover, the proper nutrient balance is essential for maintaining fruit quality in apples. An incorrect K/Ca ratio that is below the desirable levels leads to reduced shelf life and storage disorders (Tomala 1996). Ca has an important role in cell membrane integrity and cell wall resistance (Marschner 2012). Ca in particular is a decisive element for apples because they are commercially stored for long periods of time, and other factors generally do not supersede the influence of Ca on storage quality (Von Bennewitz et al. 2011). Foliar application of Ca is often used to control Ca-related disorders such as bitter pits in apples. Increasing the amount and frequency of Ca consumption immediately increases the Ca level of the fruit and can decreases Ca-related disorders and thereby improve apple quality (Kalcsits et al. 2017).

Potassium is the most plentiful mineral component in apple fruit, promoting the transportation and storage of sugar and water in fruits (Marschner 2012). Potassium deficiency results in poor color, in decreased root growth and fruit quality, as well as in burn-up and necrosis in the leaf tips and margins (Qeyami et al. 2020). Appropriate utilization of K fertilizers can motivate a significant yield increase. However, the use of excessively high rates of K can decrease the accessibility of Ca for apple trees (Kuzin et al. 2020). Inconsistent results have been obtained by various researchers when K and Ca fertilizers were used to improve the postharvest quality and storability of apple cultivars (Dilmaghani et al. 2005; Szewczuk et al. 2008; Von Bennewitz et al. 2011). These conflicting results can be due to differences in cultivars, the modes of fertilization, fertilizer source and concentration, water stress, and nutritional status of experimental soil and trees, which could affect nutrient uptake.

Among the modes of fertilization, foliar spray is recognized as a reliable approach for obtaining a quick response to fertilization of fruit trees (Swietlik and Faust 1984), particularly when soil conditions impede element uptake via the root, or during periods of rapid growth or reproductive development stages (Restrepo-Diaz et al. 2008). Solhjoo et al. (2017) evaluated the influence of preharvest foliar spray of various K fertilizers and calcium chloride ($CaCl_2$), and their combination on the fruit quality of "Red Delicious" apple and reported that combined application of $CaCl_2$ and each of the K sources was more effective in the improvement of fruit color, firmness, fruit K and Ca uptake, and K/Ca ratio at harvest time as compared to the case when either K or Ca was applied alone. Moreover, there is little information related to the effectiveness of foliar spray of important K sources (solely or combined with Ca) on postharvest quality and storability of apple cultivars in the literature. Therefore, the objective of this study was to go beyond the harvest time and investigate the effect of foliar application of various K sources (KNO_3, K_2SO_4, and KCl) and $CaCl_2$ and a combined application of some of these fertilizers on fruit color, as well as changes in fruit internal quality attributes and resistance to mechanical damages in the "Red Delicious" apple during storage time.

Material and Methods

Plant Materials and Treatments

This study was conducted through two consecutive growing seasons in a commercial apple orchard located in Kudian village, Shiraz County, Fars province, southern Iran. The experimental site exhibits dry and hot summers but cold and humid winters receiving 275 mm precipitation annually. Experimental plants were 14-year-old "Red Delicious" apple trees grafted on MM 106 rootstocks and planted at 4 × 2.5 m apart from each other. They were grown in loamy soil under a drip irrigation system and trained in a modified leader and received the usual care of local commercial apple orchards, such as pruning, pollination, nutrition, as well as weed and pest control. Before starting the research, the nutrient contents in the soil and leaves were determined (Table 1). According to Neilsen and Neilsen (2003), the

Table 1 Physical and chemical properties of soil in the experimental orchard

Soil depth (cm)	Soil texture			Cu	Mn	Zn	Fe	K	P	N	OC	TNV	SP	pH	EC
	Sand	Silt	Clay												
	%			(ppm)						(%)					(ds/m)
0–30	50	32	18	0.3	0.8	2.1	0.9	250	45	0.20	2.14	40	29	7.39	2.58
30–60	50	30	20	0.6	0.7	1.3	5.3	261	26	0.12	1.36	45	30	7.46	1.09

Soil samples were taken at 0–30 and 30–60 cm depth
N total nitrogen, *OC* organic carbon, *TNV* total neutralizing value, *SP* saturation percentage

Table 2 Leaf nutrient content of apple cultivar "Red Delicious" in the experimental orchard before starting the treatments

ppm					% dry weight		
B	Cu	Mn	Zn	Fe	K	P	N
65	5	37	10	73	1.13	0.12	1.63

A sample of 50 leaves were collected from the middle of current season shoots of 10 randomly selected trees in mid-August the year before starting of experiment

arable and sub-arable soil layers in the experimental site showed the standard levels of K, but in the leaves, it was near the deficit level or below the normal range (1.5–2.5%; Table 2).

The study was performed according to a completely randomized block design with six treatments (chemicals) and four replications, each including a whole tree, and in total consisting of 24 trees (6 treatments × 4 replications). Foliar spray treatments include sole application of three sources of K (KCl [60% K_2O, 47% Cl], K_2SO_4 [50% K_2O, 45% SO_3], and KNO_3 [44% K_2O, 14% N]), at a concentrations of 2.5 g × l^{-1} for each of their oxides (K_2O), sole application of $CaCl_2$ at a concentration of 5 g × l^{-1}, and combined application of $KNO_3 + CaCl_2$ at the aforementioned concentrations and the control. $CaCl_2$ was sprayed five times (starting from 3 weeks after full bloom with 3-week interval) and K sources were sprayed three times (at 9, 12, and 15 weeks after full bloom), in each growing season. Control trees were sprayed with water. The period of 145 days after full bloom (25 and 29 April, respectively, in the first and second season) was considered for the date of commercial harvest by performing the starch-iodine test. Fruit samples consisting of 60 fruits were randomly taken at harvest time from each replicate (each apple tree was considered as one replication) and divided into three sets of 20 fruits for three times of measurements (at harvest and stored at 0 °C [RH = 85%] for 2 and 4 months).

Fruit Color Measurement

Following harvest, the peel of five randomly selected apples from each replicate was marked at two points, 180° apart on each fruit, and color on each side was measured using a colorimeter (CR-400/410, Konica Minolta, Japan). Fruit chromaticity was recorded according to the *Commission Internationale d'Eclairage* (CIE) with parameters L* (light to dark), a* (green to red), and b*(blue to yellow) color space coordinates. Chroma C* is calculated as $(a^* + b^*)^{1/2}$. The hue angle (h°) is calculated from the arc tangent of b*/a* and expressed in degrees from 0 to 360, where 0° = red, 90° = yellow, 180° = green, and 360° = blue (McGuire 1992).

Total Soluble Solids, Titratable Acidity, Firmness, and Dry Matter

Sub-samples of five unpeeled apple fruits were used as a blended composite of wedges to determine total soluble solids (TSS) and total acidity (TA). The TSS was determined using a refractometer (ATAGO ATC-IE model, Japan) and expressed in Brix, while TA was determined using NaOH (0.3 N) according to A.O.AC. (1995). The TSS/TA ratio was also calculated. Fruit firmness (FF) was determined using a Force Gauge (FG-5005, Lutron Electronic Enterprise co. Ltd, Taiwan) on opposite sides of the five randomly selected fruits in each replicate and was expressed in Newton (N). Dry matter (DM) was determined using two plugs of 10 mm diameter excised from five randomly selected fruits in each replicate. Fruit tissue was sampled perpendicular to the fruit surface. Plugs were weighed on a preweighed foil tray. The samples were then oven-dried at 70 °C for 20 h until a constant weight was reached and were then re-weighed once more. Dry matter was expressed as the percentage of the dry weight of the initial fresh sample.

Bruise Measurement

For the bruise test, a set of five fruits was selected randomly in each replicate, then a spherical steel ball (110 g) was thrown from 30 cm into a vertical hollow porous cylinder constructed of PVC, striking the fruit on opposing sides along its equatorial axis (Banks and Joseph 1991). Fruits were left in the laboratory for roughly 24 h after testing to allow for bruise formation. Bruise sizes were determined by cutting a slice of tissue from the fruit along a vertical axis through the bruise center and down to the fruit core. A digital caliper was used to measure the diameter (d; or BD) of the bruise as well as the depth (h; or BH). Bruise volume (BV; in mm^3; Eq. 1) and general bruise susceptibility (GBS; Eq. 2; Eq. 3) were calculated based on Mohsenin (1986) as follows:

$$BV = (\pi h/24)(3d2 + 4h2) \tag{1}$$

General bruise susceptibility (GBS; mm^3J^{-1}) is defined as the ratio of bruise volume to the impact energy, IE (J):

$$GBS = BV/I \tag{2}$$

$$IE = mighD \tag{3}$$

where m_i is the mass of the impacting (or falling) object (kg), g is the acceleration due to gravity (ms^{-2}), and h_D is the drop height (m).

Table 3 Effect of preharvest foliar spray of potassium sources and calcium chloride on skin color of "Red Delicious" apple fruits, harvested in two growing seasons

	Hue angle		a*		b*		Chroma		L	
Treatment	First season	Second season	First season	Second season	First season	Second season	Second season	Second season	First season	Second season
Control	27.70 a	31.55 a	23.2 c	20.35 b	12.17 a	12.48 a	26.22 cd	23.90 c	41.75 a	42.42 b
KNO_3	21.75 c	26.55 b	25.37 b	22.65 a	10.12 b	11.30 b	27.32 bcd	25.30 ab	42.65 a	43.95 ab
K_2SO_4	22.10 c	26.80 b	26.85 a	22.95 a	10.88 b	11.58 ab	28.97 a	25.65 a	42.25 a	42.85 ab
KCl	21.17 c	26.27 b	26.00 ab	22.67 a	10.08 b	11.17 b	27.90 ab	25.25 abc	44.22 a	44.07 a
$CaCl_2$	25.10 ab	30.05 a	23.70 c	20.77 b	11.07 ab	11.95 ab	26.17 d	23.97 bc	44.02 a	43.97 ab
KNO_3+CaCl_2	22.82 bc	26.90 b	25.25 b	22.55 a	10.60 b	11.42 b	27.37 bc	25.27 abc	41.80 a	42.80 ab
LSD (0.05)	2.80	2.44	1.22	1.48	1.29	0.91	1.2	1.38	Ns	Ns

Data followed by the same letter in the column are not significantly different according to LSD test ($p \leq 0.05$)

Weight Loss

Weight loss (WL) was recorded during storage, using five fruits per replicate, calculated as follows:

$$Weight\,loss = ((Wi - Wf)/Wi) \times 100 \quad (4)$$

W_i being the initial sample weight and W_f the final sample weight. Results are reported as percentage of weight loss.

Analysis of Fruit Mineral Concentration

In order to analyze the fruit mineral composition, two longitudinal slices were obtained from each fruit (10 fruits per replicate), including the peel. Samples were dried in an oven at 75 °C for 72 h. Then ash was produced at 500 °C for 8 h, dissolved in 5 ml of 2N HCl and filtered using a filter paper. Finally, the ashes were diluted to a volume of 50 ml with deionized water. The concentration of K was measured using flame photometry (Jenway-PFP7, England) at 766.5 nm (Chapman and Pratt 1961) and Ca was estimated using an atomic absorption spectrophotometer (Shimadzu-AA-670, Japan) at 422.7 nm (Waling et al. 1989) and. The results are expressed as $mg \times kg^{-1}$ dry weight.

Statistical Analysis

Statistical analysis was performed using SAS software (version 9.1) according to a randomized complete block design (RCBD) within repeated measurement design having four replications. Primarily, the data of two growing seasons were compared to evaluate the significance of the year effect. Results showed that the effect of year was significant for almost all measured traits at $p \leq 5\%$, except for TSS, TA, and WL. Thus, the data of 2 years were averaged in the case of a nonsignificant year effect, while the 2-year data are presented for others. Data were analyzed using the GLM procedure and mean values were compared by the LSD test at a significance level of 0.05. To illustrate the association among fruit quality attributes as well as between nutrient concentrations and fruit quality characteristics, the correlations between all measured traits of "Red Delicious" apple fruits (generated based on the average data of two growing seasons) were calculated based on Pearson's correlation coefficient.

Results and Discussion

Fruit Color

As shown in Table 3, the sole application of K sources in addition to a combined spray with $KNO_3 + CaCl_2$ significantly enhanced the rate of skin color development as compared to the control fruits; however, the sole application of $CaCl_2$ had a little effect on fruit color. There were no significant differences in fruit color properties between trees that received different types of K fertilizers. Treatments with K sources significantly decreased the h° and increased a* value and C*, indicating that K sources increased the fruit peel red color and decreased the yellow color of "Red Delicious" apple. The b* value and h° of the control trees were higher than those of treated trees, indicating the yellow color of the fruits in these treatments. L* was not clearly affected significantly by the treatments; however, it was lower in control trees. Results showed a positive correlation ($R = 0.98$) between a* value and C* value and also between b* value and h° ($R = 0.64$). Moreover, K concentration was negatively correlated with a* value ($R = -0.51$) (Table 4). Chroma is the intensity or purity of the h° and it shows the brightness of fruits. Therefore, K treatments increased the color brightness compared to the control. Nava et al. (2008) have reported that K fertilization increased the a* value and reduced the b* value of "Fuji" apples, which is in agreement with the results of this research. Kadir (2005) also reported lower hue angle in Ca-treated fruits of "Jonathan" apple. Abdel-Hafeez et al. (2010) found

Table 4 Correlations among all measured traits of "Red Delicious" apple fruits treated with preharvest foliar spray of potassium sources and calcium chloride (generated based on average data of two growing seasons)

	F	TSS	TA	TSS/TA	DM	GBS	WL	BD	BH	BV	a*	b*	L*	h	C*	K	Ca	K/Ca
Firmness (F)	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total soluble solids (TSS)	–0.56**	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Titratable acidity (TA)	0.73**	–0.38**	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
TSS/TA	–0.80**	0.69**	–0.91**	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dry matter (DM)	–0.76**	0.57**	–0.62**	0.71**	1	–	–	–	–	–	–	–	–	–	–	–	–	–
General bruise susceptibility (GBS)	0.28**	–0.12	0.32**	–0.28**	–0.31**	1	–	–	–	–	–	–	–	–	–	–	–	–
Weight loss (WL)	–0.77*	0.43**	–0.70**	0.71**	0.79**	–0.30**	1	–	–	–	–	–	–	–	–	–	–	–
Bruise diameter (BD)	0.10	–0.15	0.12	–0.16*	–0.22**	0.30**	0.04	1	–	–	–	–	–	–	–	–	–	–
Bruise depth (BH)	0.29**	–0.30**	0.19*	–0.27**	–0.28**	0.17*	–0.02	0.78**	1	–	–	–	–	–	–	–	–	–
Bruise volume (BV)	0.17*	–0.19*	0.09	–0.17*	–0.15	0.10	0.12	0.80**	0.90**	1	–	–	–	–	–	–	–	–
a*	–0.02	–0.11	–0.12	0.04	–0.16*	0.08	0.22**	0.37**	0.40**	0.34**	1	–	–	–	–	–	–	–
b*	–0.01	0.05	0.04	–0.02	0.14	–0.08	0.06	0.28**	0.38**	0.56**	–0.33**	1	–	–	–	–	–	–
L*	–0.01	–0.18*	–0.01	–0.07	–0.01	–0.17*	0.23**	0.40**	0.39**	0.50**	0.05	0.25**	1	–	–	–	–	–
H	–0.01	–0.02	–0.02	–0.01	0.09	–0.07	0.03	0.09	0.18*	0.27**	–0.34**	0.64**	0.19*	1	–	–	–	–
C*	–0.02	–0.10	–0.14	0.05	–0.15	0.08	0.23**	0.38**	0.44**	0.40**	0.98**	–0.24**	0.01	–0.29**	1	–	–	–
Potassium (K)	0.01	–0.03	0.03	–0.02	0.20*	–0.13	0.13	–0.03	–0.05	0.04	–0.51**	0.23**	0.32**	0.24*	–0.48**	1	–	–
Calcium (Ca)	0.33**	0.13	–0.32**	0.31**	0.47**	–0.33**	0.43**	–0.18*	0.01	–0.05	–0.01	–0.06	0.13	–0.03	0.01	0.20*	1	–
K/Ca ratio	–0.36**	–0.15	0.34**	–0.33**	–0.45**	0.31**	–0.43**	0.16	–0.03	0.05	–0.1	0.12	–0.09	0.08	–0.11	–0.03	–0.97**	1

*, **Statistically significant at $p \leq 0.05$ and $p \leq 0.01$, respectively

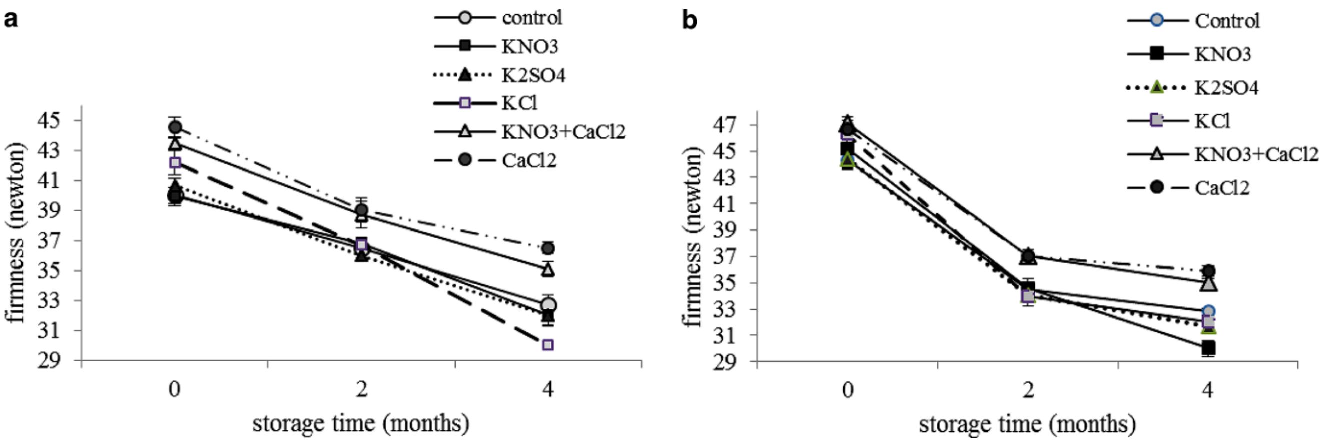

Fig. 1 Changes in fruit firmness of "Red Delicious" apple during storage time treated with preharvest foliar spray of potassium sources and calcium chloride. **a**,**b** First and second season data, respectively

that KCl and $CaCl_2$ treatments had the least significant values of hue angle on plum, but KNO_3 and other Ca fertilizers had no effect on fruit color properties. Qeyami et al. (2020) demonstrated that varying concentrations of $CaCl_2$ and K_2SO_4 improved the color of apples. Optimum levels of K can enhance phloem loading, transporting, and unloading of sucrose (Marschner 2012). Furthermore, K is involved in a variety of enzymatic activities and is a key component in the formation of fruit color (Gill et al. 2012; Tripathi and Uniyal 2018). Therefore, it becomes apparent that sugar translocation into the fruit is aided by K, which is necessary for the production of polyphenols like anthocyanin (Solhjoo et al. 2017).

Fruit Firmness

As expected, the FF decreased significantly ($p<0.05$) through the storage period (Fig. 1a,b). In both years, trees treated with $CaCl_2$ and KNO_3+CaCl_2 produced firmer fruits compared to the control during the storage period, which is in agreement with results reported by Dilmaghani et al. (2005), Ajender and Chawla (2019), and Ranjbar et al. (2020). Significant positive correlations ($R=0.73$) were found between the FF and TA in this study, while the FF had significant negative correlations with the TSS, TSS/TA, DM, and WL ($R=$–0.5, –0.8, –0.76, –0.77, respectively) (Table 4). This finding is in agreement with the results of other researchers who reported a correlation between citrus fruit weight loss and FF (Khorram et al. 2017). Shirzadeh et al. (2011) also showed that Ca regulated the peroxidase and catalase enzymes activity in apple fruits, thus reducing physiological disorders by delaying cell breakdown and preserving better firmness and lower weight loss during storage. Also, FF decreases due to the breakdown of a major component of the cell wall (insoluble protopectins) into water-soluble pectin composites during storage, which eventually affects the cell wall stability or skin softening (Tripathi et al. 2019). Calcium acts as an intermolecular binder material to fix the protein–pectin complexes of the middle lamella. In the cell wall, Ca interacts with pectic acid to form Ca pectate, which maintains the structure of the cell wall (Ranjbar et al. 2020). These results are in line with the findings of Qeyami et al. (2020), who reported that foliar spray of Ca enhances the firmness of apples. Also, the beneficial effect of Ca dips (2% w/v) (solely or combined with hot water) on the firmness of kiwifruit during storage has been reported by Shahkoohmahali and Ramezanian (2015). Other researchers have observed the positive effect of Ca on FF in different apple cultivars (Fallahi et al. 1988; Benavides et al. 2002; Neilsen et al. 2005). By contrast, Von Bennewitz et al. (2011) showed that apple firmness was not affected by soil application of $CaSO_4$ and K_2SO_4 (each being used alone or in combination) during storage. Our results in both seasons revealed that the separate application of KNO_3 or K_2SO_4 caused no significant differences in FF for up to 2 months after harvest, compared to the control, but at the end of the storage period (4 months) the control samples showed higher FF compared to those treated with KNO_3 and KCl, respectively, in the first and second seasons, (Fig. 1a,b). Also, KCl-treated trees produced firmer fruits only at harvest time. Szewczuk et al. (2008) reported that soil application of different K fertilizer forms did not cause any significant changes in FF of "Golden Delicious" apple after storage. However, the positive effect of K on apricot firmness has been reported in the study by Moradinezhad and Dorostkar (2021). Potassium preserves water content in the tissues and thus leads to FF and strength (EL-Seginy 2006). Fruit resistance to penetration occurs in the presence of K, which may be due to an increase in the thickness of the sclerenchyma cell wall (Fallah et al. 2021).

Total Soluble Solids

The TSS of fruit was increased significantly ($p<0.05$) by prolonging the storage period (Fig. 2). The TSS levels significantly increased by KNO_3+CaCl_2 treatment only at harvest time and then stabilized during the storage period. Treatment with $CaCl_2$ did not affect TSS levels during storage. In general, fruits in the control treatment yielded the lowest TSS value at harvest and during storage, while the sole application of K sources showed the highest TSS during storage. The positive correlation was observed between TSS with TSS/TA ratio and DM ($R=0.69$ and $R=0.57$, respectively). Changes in TSS during the storage period are a result of two aspects: respiration rates and water loss by evaporation. An increase in fruit TSS with soil application of K has previously been reported by other researchers (Dilmaghani et al. 2005; Von Bennewitz et al. 2011). These findings are not in line with the results of Ranjbar et al. (2020), who reported that Ca treatments in "Red Delicious" apple resulted in low TSS compared to the control. The role of K in increasing fruit TSS might be attributed to its participation in sugar translocation from leaves to fruits (Prasad et al. 2015), resulting in higher-quality fruits with increased TSS (Qeyami et al. 2020). Inconsistent observations regarding the "Golden Delicious" apple suggest that the different forms of K fertilizers in the soil do not result in any significant effects in TSS after storage (Szewczuk et al. 2008).

Total Acidity

As shown in Fig. 3, data indicated that TA decreased with the progress in storage period up to the 4 months of storage in all treatments. The same results have been reported by Ranjbar et al. (2020) on "Red Delicious" apple. The TA increased with all K sources (~0.61%) as compared to the control (0.52%) just at harvest, but the KNO_3+CaCl_2 treatment significantly rendered more organic acids in the fruit than those of the control treatment until the end of storage.

The application of Ca delays fruit ripening (Mosa et al. 2015) and reduces ethylene production and the respiration rate, thereby reducing the rate of TA changes (Ranjbar et al. 2018, 2020). Decreased acidity may be related to postharvest ripening, because organic acids are involved in respiratory metabolism (Valero and Serrano 2010). These results are in agreement with results of Abdel-Hafeez et al. (2010), who found that spraying KNO_3 on plum can lead to higher percentages of TA throughout the storage period. Some reports showed that the preharvest application of Ca has no substantial effect on the content of organic acids in grape (Ciccarese et al. 2013) and blueberry (Angeletti et al. 2010) during storage. In another study, Prasad et al. (2015) observed increased TA content in mango by foliar application of $CaCl_2$ and KNO_3. Therefore, it can be concluded that preharvest spray of K-containing treatments can maintain the sensory quality of apple fruit.

Dry Matter

The DM percentage showed a significant increase as a result of prolonged storage periods in both seasons (Fig. 4), but this increase was slower for the control treatment during the first and second seasons. During storage, fruit DM was significantly increased by all K sources and KNO_3+CaCl_2 treatments compared to the control in both seasons. Also, during storage, control treatment exhibited the lowest DM in both seasons. During the second season, the $CaCl_2$ treatment showed a significantly higher percentage of DM as compared to the control. This result could be related to the increase in TSS content, which was affected by the K treatments. The high level of sugar and organic acids brings about an increase in the amount of the fruit DM, which acts as one of the significant factors in ameliorating the quality of fruits. Furthermore, the increased DM that is associated

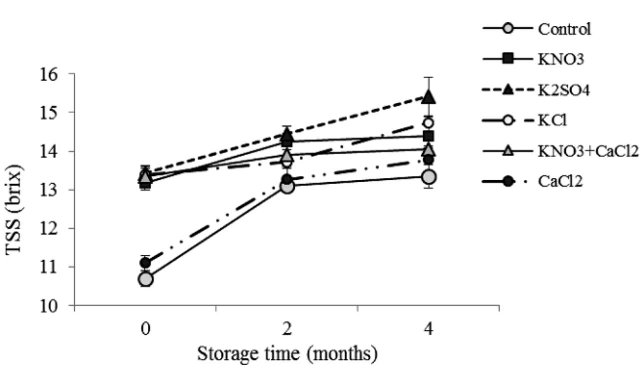

Fig. 2 Changes in TSS of "Red Delicious" apple during storage time treated with preharvest foliar spray of potassium sources and calcium chloride (as the effect of the year was not significant for this trait, data represent the average of two growing seasons)

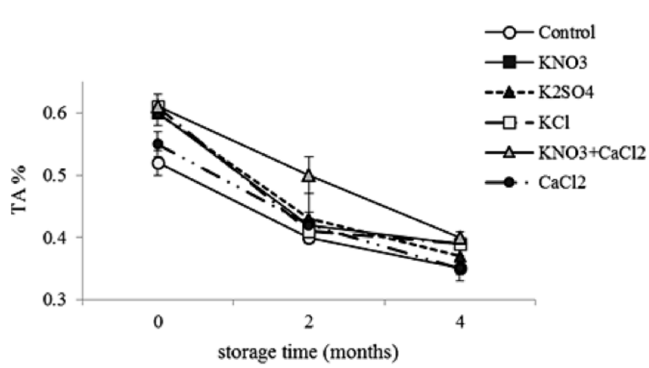

Fig. 3 Changes in titratable acidity of "Red Delicious" apple during storage time treated with preharvest foliar spray of potassium sources and calcium chloride (as the effect of year was not significant for this trait, data represent the average of two growing seasons)

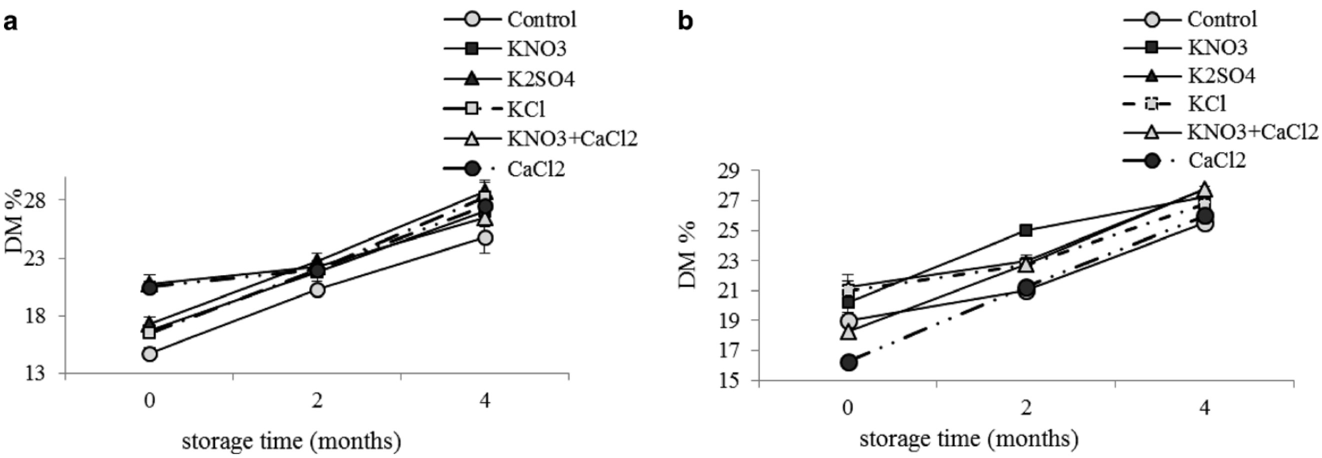

Fig. 4 Changes in dry matter of "Red Delicious" apple during storage time treated with preharvest foliar spray of potassium sources and calcium chloride. **a**,**b** First and second season data, respectively

with improved cell resources results in longer postharvest life. It has been reported that DM affects fruit quality during storage (Buxton 2005) and "Hayward" kiwifruits with low DM showed more imminent collapse, softening, and decay during storage (Ferguson et al. 2003).

Weight Loss

Weight loss increased significantly with the prolongation of the storage period (Fig. 5). This increase was more rapid in the control group than other treatments. All treatments significantly reduced WL as compared to the control treatment at the end of storage, and the control and the $KNO_3 + CaCl_2$ treatments showed the highest and lowest WL at the end of storage, respectively. These findings were comparable to those of Ranjbar et al. (2018) and Ajender and Chawla (2019), who reported that an increased storage period leads to higher weight loss in apple. The positive role of Ca in reducing WL has been reported in many studies (Mahajan and Dhatt 2004; Ashour 2000; Shirzadeh et al. 2011). Normally, WL occurs during storage due to the fruit respiration process, the transference of humidity, and a mild process of oxidation (Ayranci and Tunc 2003). Calcium ions increase the stability of cell walls by binding non-esterified pectin (Angeletti et al. 2010) and maintain integrity and functionality of the membrane (Saure 2005; Shirzadeh et al. 2011). Despite the fact that plant cell walls are permeable to water, slower breakdown of the cell-wall structure might lead to increased resistance to water flux (Angeletti et al. 2010) and, as is common knowledge, K prevents water loss and WL by increasing the fruit sugar concentration or accordingly may result in osmoregulation effects in the tissue. Shirzadeh et al. (2011) reported that application of Ca delays cells breakdown, maintaining the higher firmness and reducing WL during storage by influencing the activity of catalase and peroxidase enzyme in the apple.

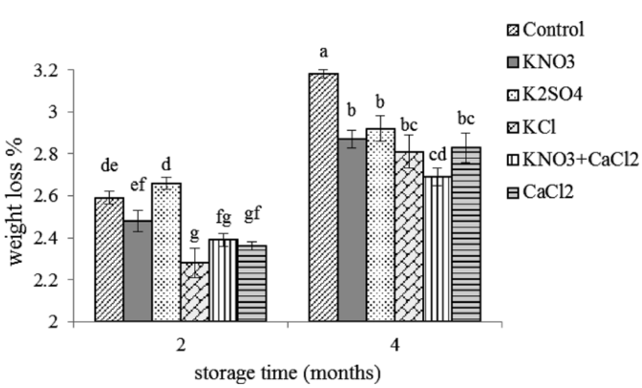

Fig. 5 Changes in weight loss of "Red Delicious" apple during storage time treated with preharvest foliar spray of potassium sources and calcium chloride (as the effect of year was not significant for this trait, data represent the average of two growing seasons)

Bruise Susceptibility

In both growing seasons, BD, BH, BV, and GBS of treated and nontreated fruits significantly decreased during the first 2 months of storage and then remained almost constant until the end of the storage period (Figs. 6, and 7 and 8 and 9). In fact, fruits were more susceptible to bruise damage at harvest time, but this tended to decrease as the time of storage increased. This necessitates caution in the handling process to protect this apple variety from impact damage at harvest and during initial storage (Gharaghani and Shahkoomahally 2018). Contrary to our findings, Abi Tarabay et al., (2018) reported that bruising percent increased with prolonged storage time. As shown in Figs. 6 and 7 and 8 and 9, nonsignificant differences were observed between treatments in both growing seasons except at harvest time in the second growing season when fruits treated with KCl showed the highest bruise susceptibility. The values of BH, BV, and GBS were significantly higher for the KCl-treated

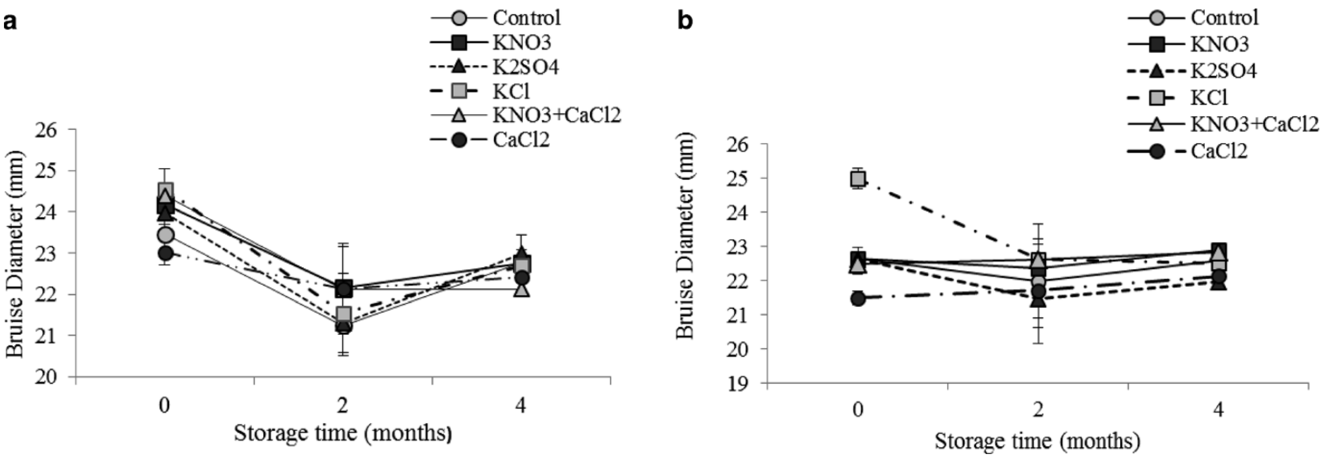

Fig. 6 Changes in bruise diameter of "Red Delicious" apple during storage time treated with preharvest foliar spray of potassium sources and calcium chloride. **a**,**b** First and second season data, respectively

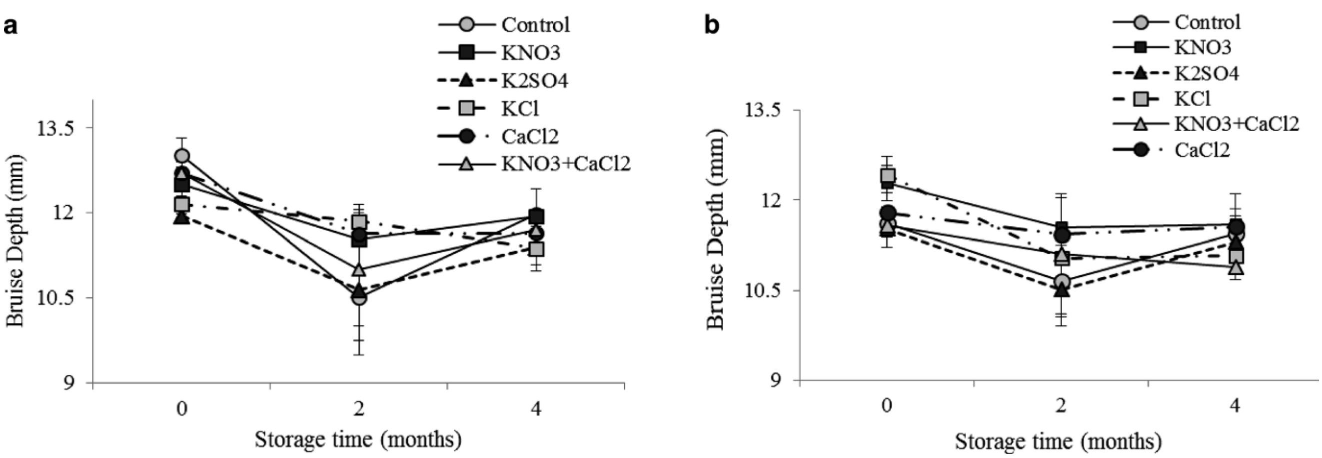

Fig. 7 Changes in bruise depth of "Red Delicious" apple during storage time treated with preharvest foliar spray of potassium sources and calcium chloride. **a**,**b** First and second season data, respectively

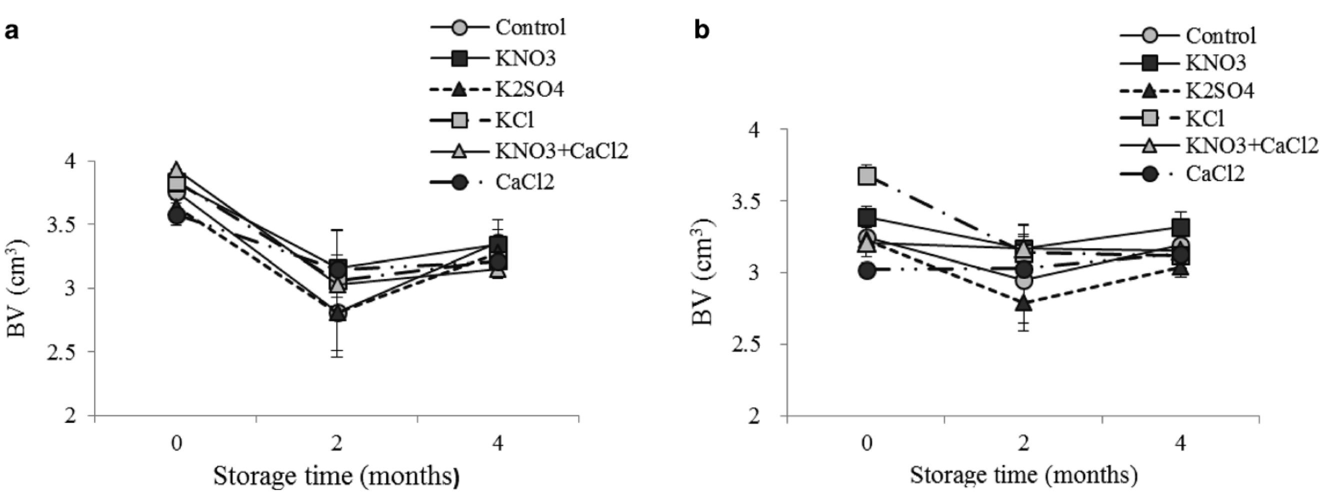

Fig. 8 Changes in bruise volume (*BV*) of "Red Delicious" apple during storage time treated with preharvest foliar spray of potassium sources and calcium chloride. **a**,**b** First and second season data, respectively

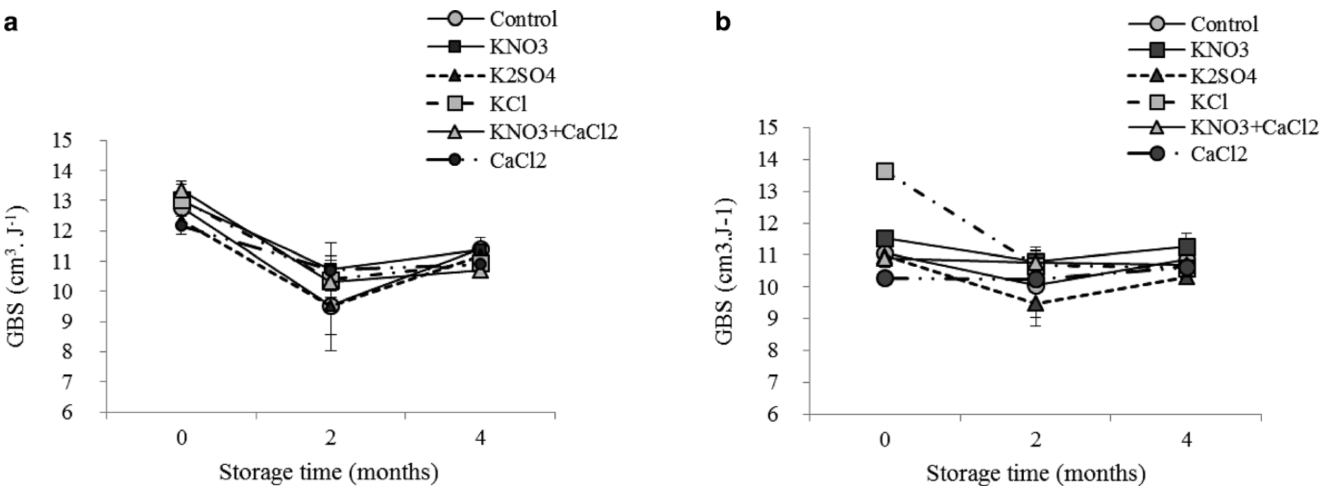

Fig. 9 Changes in general bruise susceptibility (*GBS*) of "Red Delicious" apple during storage time treated with preharvest foliar spray of potassium sources and calcium chloride. **a**,**b** First and second season data, respectively

fruits than the control only at harvest time (Figs. 7b, and 8b, and 9b). In general, the bruise was not influenced effectively by K and Ca treatments. Although Ca had no effect on bruise reduction in this study, a decrease in the BS in Ca $(NO_3)_2$-treated apples was reported in the study by Jafarian et al. (2021). They also observed the highest BS in untreated trees on the first day. Similarly, Tahir and Ericsson (2001) observed a positive effect of Ca application on BS reduction.

Correlation analysis showed that there is a strong positive correlation ($R=0.90$) between BH and BV. In addition, the BH and BV in the fruit had significantly positive correlation ($R=0.78$ and $R=0.8$, respectively) with the BD. A positive correlation was recorded for BV ($R=0.56$) with b* (Table 4). The tendency of lower susceptibility to bruise damage in the latter stages of storage can be explained by the differences in turgidity and the increased fruit skin resistance as well as the change in the fruit texture during storage (Van Zeebroeck et al. 2007). The same patterns have been noted by Yurtlu and Erdogan (2005) whereby BV and BS of "Starkspur Golden Delicious" apple and "Williams" pear decrease with increased storage time.

Fruit Mineral Concentration

In general, the K concentration of fruits increased by spraying treatments with K sources (solely or along with $CaCl_2$) compared to the control trees. However, the highest values of K concentration of fruit were observed in K_2SO_4 and KCl in first and second season, respectively (Table 5). In both seasons, the lowest K concentration of fruit was recorded in the control fruits. A noticeable increase of the K concentration was also recorded in single treatment of $CaCl_2$ compared to untreated control trees (Table 3). The K concentration in fruit was correlated with some of the fruit color attributes (Table 4). A positive and significant correlation ($R=0.32$) was observed between K concentration and L*, while negative associations were seen between K and a* ($R=-0.51$) and K and c* ($R=-0.48$). Kadir (2005), applying a foliar spray of $CaCl_2$ (4 and 8 times, 9 kg ha^{-1} during the growing season), reported significantly enhanced

Table 5 Effect of preharvest foliar spray of potassium sources and calcium chloride on concentrations of potassium (K), calcium (Ca), and K/Ca ratio in treated "Red Delicious" apples, harvested in two growing seasons

Treatments	K (mg × kg^{-1} DW)		Ca (mg × kg^{-1} DW)		K/Ca ratio	
	First season	Second season	First season	Second season	First season	Second season
Control	7451.5c	7686.5c	276.48b	321.5c	26.5b	24.25b
$CaCl_2$	7671b	7971b	374.05a	408.55b	20.5c	19.5c
KNO_3	7793ab	8147ab	271.98b	313.98c	28.7a	26.25a
K_2SO_4	7978.8a	8120.3ab	290.33b	305.33c	29.5a	27.5a
KCl	7870.3ab	8278.8a	371.43a	412.43b	21.5c	20.5c
$KNO_3 + CaCl_2$	7774.5ab	8074.5b	366.4a	556.4a	21.0c	15.0d
LSD (0.05)	212.5	200.4	34.47	71.25	5.95	4.43

Data followed by the same letter in the column are not significantly different according to LSD test ($p \le 0.05$)

K concentrations in the peel and flesh of "Jonathan" apples, which is in accordance with the results of current study.

The highest fruit Ca concentration was recorded in fruits treated with $CaCl_2$ (solely or $KNO_3 + CaCl_2$) as well as KCl. On the other hand, the lowest Ca levels were found in control fruits and other K sources in both growing seasons (Table 4). Spraying solely KCl resulted in an increased fruit Ca concentration compared to other K sources. Consistent with the results of this study, increased apple fruit Ca content as a result of preharvest Ca treatment has been reported in several studies (Benavides et al. 2002; Neilsen and Neilsen 2001; Jafarpour and Poursakhi 2011). Similarly, Asgharzade et al. (2012) stated that the Ca content of apples treated with $CaCl_2$ was increased, which confirms the results of this study.

Chloride (in the form of KCl fertilizer) may act as a neutralizer ion, balancing inorganic cations such as Ca^{+2} and resulting in improved Ca mobility and transfer to the fruit. An antagonistic effect between K and Ca has been reported in the soil, which means use of K fertilizer can reduce the absorption of Ca by the roots (Neilsen and Neilsen 2003; Dilmaghani et al. 2005). However, it appears that this antagonistic action was formed only in the soil, not within the plant. Foliar treatment of K and Ca revealed no antagonistic interaction in this investigation. Not surprisingly, Ca concentration was positively correlated with FF ($R = 0.33$) and negatively correlated with GBS ($R = -0.33$), meaning that the fruit with higher Ca was firmer and less susceptible to mechanical damage (Table 4).

Over the two consecutive cropping seasons, the trend of K/Ca ratios was different. In general, $CaCl_2$ (solely or combined with KNO_3) as well as KCl produced a lower K/Ca ratio than the control or other treatments (Table 5). The highest ratio belonged to KNO_3 (in the first growing season) and K_2SO_4 (in both growing seasons) treatments (29 and 28, respectively). The K/Ca ratio of the control trees was approximately 25. Therefore, the sole application of $CaCl_2$ or the combination of KNO_3 and $CaCl_2$ led to the more appropriate ratio (approximately 15 ~ 21) than single K sources application (22 ~ 29). Ratios of K/Ca < 28 and K/Ca < 30 have been recommended for apple in Poland and Italy, respectively (Piestrzeniewicz and Tomala 2000; Drahorad and Aichner 2001). Given the K/Ca ratios reported in this study, foliar application of $CaCl_2$ might be recommended for optimizing the ratio when K fertilizers are applied in an apple orchard. Due to the diluting effect, apple trees with a reduced fruit load would yield bigger fruits with lower Ca contents (Fallahi and Simons 2008). However, in the current study, bigger fruit were found in trees that received Ca coupled with KNO_3 treatments, as well as greater K and Ca concentrations. As a result, rather than yield impacts, this higher absorption should constitute a real treatment effect. Interestingly, the K/Ca ratios were negatively correlated with FF ($R = -0.36$) and positively correlated with GBS ($R = 0.31$), which means fruit with a higher K/Ca ratio was less firm and more prone to mechanical damage (Table 4).

Conclusion

The results obtained in the present study indicate that none of the sole applications of K sources and Ca could effectively improve storability, while the best results were obtained when the combination of KNO_3 and $CaCl_2$ was applied. Thus, foliar application of K combined with Ca could positively affect postharvest quality of apple. Considering different sources of K, foliar spray of KCl was more effective in fruit quality only at harvest, but there were no significant differences between K sources after 4 months of storage. Also, results showed that the "Red Delicious" apple is more susceptible to bruise damage at harvest time. This means that the handling of fruits at harvest and during the initial phases of storage require special attention to protect this variety from impact damage.

Acknowledgements We would like to thank Arya Sam Company (cold storage and fruit marketing) for supporting the experimental apple orchard and cold storage facilities for this project. We would also like to thank Mohsen Hamedpour-Darabi for help with the language of the paper.

Author Contribution We confirm that all authors contributed significantly to the work and agree with the contents of the manuscript and its submission to the journal. Sahar Solhjoo conducted all the experiments and generated the data, performed parts of statistical analysis, and wrote the first draft of the manuscript. Ali Gharaghani designed all experiments, provided materials, supervised the practical issues related to the data collection and analysis, revised and improved the first draft of manuscript. Mansoureh Nazari performed parts of the statistical analysis and partially contributed to the writing of the first draft.

Conflict of interest S. Solhjoo, A. Gharaghani and M. Nazari declare that they have no competing interests.

References

A.O.A.C. (1995) Official methods of analysis, 16th edn. Association of Official Analytical Chemists International, Arlington

Abdel-Hafeez AA, Mohamed AI, Taher NM, Mehaisen SMA (2010) Effects of some sources of potassium and calcium as a foliar spray on fruit quality and storability of "Kelsey" plums. Egypt J Hortic 2:151–168

Ajender TB, Chawla W (2019) Effect of calcium chloride on growth, fruit quality and production of apple. J Pharmacogn Phytochem 1(2):588–593

Angeletti P, Castagnasso H, Miceli E, Terminiello L, Concellón 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 Biol Technol 58(2):98–103

Asgharzade A, Valizade GA, Babaeian M (2012) Effect of Calcium Chloride (CaCl2) on some quality characteristic of apple fruits in Shirvan region. Afr J Microbiol Res 6(9):2000–2003

Ashoori M, Lolaei A, Zamani S, Ahmadian E, Mobasheri S (2013) Optimizing quality and quantity-parameters of apple cv. 'Red Delicious' by adjustment of Calcium and Nitrogen. Int J Agric Crop Sci 5(8):868

Ashour NN (2000) Effect of environmental factors, calcium and potassium fertilization on yield and quality of apple. Doctoral dissertation. Fac. Agric. Mansoura Univ

Ayranci E, Tunc S (2003) A method for the measurement of the oxygen permeability and the development of edible films to reduce the rate of oxidative reactions in fresh foods. Food Chem 80(3):423–431

Banks NH, Joseph M (1991) Factors affecting resistance of banana fruit to compression and impact bruising. J Sci Food Agric 56(3):315–323

Benavides A, Recasens I, Casero T, Soria Y, Puy J (2002) Multivariate analysis of quality and mineral parameters on Golden Smoothee apples treated before harvest with calcium and stored in controlled atmosphere. Food Sci Technol Int 8(3):139–146

Buxton KN (2005) Preharvest practices affecting postharvest quality of 'Hayward' kiwifruit: a thesis presented in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Plant Physiology and Horticultural Science at Massey University, New Zealand

Chapman HD, Pratt PF (1961) Methods of analysis for soils, plants and waters. University of California, Los Angeles, 60–61, 150–179.

Ciccarese A, Stellacci AM, Gentilesco G, Rubino P (2013) Effectiveness of pre-and post-veraison calcium applications to control decay and maintain table grape fruit quality during storage. Postharvest Biol Technol 75:135–141

Dilmaghani MR, Malakouti MJ, Neilsen GH, Fallahi E (2005) Interactive effects of potassium and calcium on K/Ca ratio and its consequences on apple fruit quality in calcareous soils of Iran. J Plant Nutr 27(7):1149–1162

Drahorad W, Aichner M (2001) Development and evaluation of a bitter pit prognosis model in apple orchards in the south Tyrol (northern Italy). Acta Hortic 564:91–96

EL-Seginy A (2006) Response of „Canino" apricot trees to different irrigation and potassium treatments. Alex Sci Exch 27(1):64

Ericsson NA, Tahir I (1996) Studies on apple bruising: I. Estimation of incidence and susceptibility differences in the bruising of three apple cultivars. Acta Agric Scand B Plant Soil Sci 46:209–213

Fallah M, Delshad M, Sheikhi H (2021) The effects of cluster pruning and the K: N ratio on greenhouse tomato yield and quality. Hortic Environ Biotechnol 62(5):691–700

Fallahi E, Simons BR (2008) (1993) Effects of rootstock and thinning on yield fruit quality and elemental composition of 'Redspur Delicious' apple. Commun Soil Sci Plant Anal 24(7–8):589–601. https://doi.org/10.1080/00103629309368825

Fallahi E, Righetti TL, Raese JT (1988) Ranking tissue mineral analysis to identify mineral limitations on quality in fruit. J Am Soc Hort Sci 113(3):382–389

Ferguson IB, Thorp TG, Barnett AM, Boyd LM, Triggs CM (2003) Inorganic nutrient concentrations and physiological pitting in Hayward kiwifruit. J Hortic Sci Biotechnol 78(4):497–504

Garcia JL, Ruiz Altisent M, Barreiro P (1995) Factors influencing mechanical properties and bruise susceptibility of apples and pears. J Agric Eng Res 61:11–18

Gharaghani A, Shahkoomahally S (2018) Effects of fruit size and cultivar on bruise susceptibility and some physical properties of apple fruit. Iran Agric Res 37(1):49–56

Gill PPS, Ganaie MY, Dhillon WS, Singh NP (2012) Effect of foliar sprays of potassium on fruit size and quality of 'Patharnakh'pear. Ind J Hortic 69(4):512–516

Iglesias I, Salvia J, Torguet L, Cabus C (2002) Orchard cooling with over tree microsprinkler irrigation to improve fruit color and quality of 'Topred Delicious' apples. Sci Hortic 93:39–51

Jafari R, Nassiri SM (2013) Modeling static bruising in apple fruits: acomprative study, part II: finite element approach. Iran Agric Res 32(2):11–20

Jafarian M, Emami H, Motie BJ (2021) Effect of Ca (NO3) 2 coating on chemical and mechanical properties and bruise susceptibility of Golden Delicious and Red Delicious apples during storage. Acta Aliment 50(3):404–416

Jafarpour M, Poursakhi K (2011) Study of concurrent effect of using nutrients through soil and foliar application on yield and quality of the "Red Delicious" apple. In: International Conference on Life Science and Technology IPCBEE. vol 3, pp 87–96

Kadir SA (2005) Fruit quality at harvest of "Jonathan" apple treated with foliarly-applied calcium chloride. J Plant Nutr 27(11):1991–2006

Kalcsits L, Van der Heijden G, Reid M, Mullin K (2017) Calcium absorption during fruit development in 'Honeycrisp'apple measured using 44Ca as a stable isotope tracer. HortScience 52(12):1804–1809

Khan AS, Ali S (2018) Preharvest sprays affecting shelf life and storage potential of fruits. In: Sidiqqui MW (ed) Pre-harvest modulation of postharvest fruit and vegetable quality, pp 209–255

Khorram F, Ramezanian A, Hosseini SMH (2017) Shellac, gelatin and Persian gum as alternative coating for orange fruit. Sci Hortic 225:22–28

Kuzin AI, Kashirskaya NY, Kochkina AM, Kushner AV (2020) Correction of potassium fertigation rate of apple tree (Malus domestica Borkh.) in central Russia during the growing season. Plants 9(10):1366

Lara I (2013) Preharvest sprays and their effects on the postharvest quality of fruit. Stewart Postharvest Rev 9:1–12

Mahajan BVC, Dhatt AS (2004) Studies on postharvest calcium chloride application on storage behaviour and quality of Asian pear during cold storage. J Food Agric Environ 2(3–4):157–159

Marschner P (2012) Mineral nutrition of higher plants, 3rd edn. Academic Press (651 p)

McGuire RG (1992) Reporting of objective color measurements. HortScience 27(12):1254–1255

Mohsenin NN (1986) Physical properties of plant and animal materials structure, physical characteristics and mechanical properties, 2nd edn. Gordon and Breach Science Publishers

Moradinezhad F, Dorostkar M (2021) Pre-harvest foliar application of calcium chloride and potassium nitrate influences growth and quality of apricot (Prunus armeniaca L.) fruit cv. 'Shahroudi'. J Soil Sci Plant Nut 21(2):1642–1652. https://doi.org/10.1007/s42729-021-00468-2

Mosa WFAEG, EL-Megeed ANA, Paszt LS (2015) The effect of the foliar application of potassium, calcium, boron and humic acid on vegetative growth, fruit set, leaf mineral, yield and fruit quality of 'Anna' apple trees. J Exp Agric Int 8(4):224–234

Nava G, Roque-Dechen A, Ribeiro-Nachtiga G (2008) Nitrogen and potassium fertilization affect apple fruit quality in southern Brazil. Commun Soil Sci Plant Anal 39:96–107

Neilsen GH, Neilsen D (2001) Effect of foliar Zn, form and timing of Ca sprays on fruit Ca concentration in new apple cultivars. In: International Symposium on Foliar Nutrition of Perennial Fruit Plants, vol 594, pp 435–443

Neilsen GH, Neilsen D (2003) Nutritional requirements of apple. In: Ferree DC, Warrington IJ (eds) Apples: botany, production and uses. CABI, p 660

Neilsen G, Neilsen D, Dong S, Toivonen P, Peryea F (2005) Application of CaCl2 sprays earlier in the season may reduce bitter pit incidence in 'Braeburn' apple. HortScience 40(6):1850–1853

Piestrzeniewicz C, Tomala K (2000) Some factors influencing storage ability of „Jonagold" apples. Acta Hortic 564:435–442

Prasad BC, Dimri D, Bora L (2015) Effect of pre-harvest foliar spray of calcium and potassium on fruit quality of Pear cv. Pathernakh. Sci Res Essays 10(11):376–380. https://doi.org/10.5897/SRE2015.6246

Qeyami M, Bajpay A, Jailani AW (2020) Effects of Calcium and Potassium application on growht, yield and quality of apple (Malus x domestica Borkh.) cv. Red Delicious. Ind J Pure App Biosci 8(3):574–584

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. Sci Hortic 240:57–64

Ranjbar S, Ramezanian A, Rahemi M (2020) Nano-calcium and its potential to improve 'Red Delicious' apple fruit characteristics. Hortic Environ Biotechnol 61(1):23–30

Restrepo-Diaz H, Benlloch M, Navarro C, Fernández-Escobar R (2008) Potassium fertilization of rainfed olive orchards. Sci Hortic 116(4):399–403

Saure MC (2005) Calcium translocation to feshy fruit: its mechanism and endogenous control. Sci Hortic 105:65–89

Shahkoomahally S, Ramezanian A (2015) Hot water combined with calcium treatment improves physical and physicochemical attributes of kiwifruit (Actinidia deliciosa cv. Hayward) during storage. HortScience 50(3):412–415

Shirzadeh E, Rabiei V, Sharafi Y (2011) Effect of calcium chloride (CaCl2) on postharvest quality of apple fruits. Afr J Agric Res 6(22):5139–5143

Solhjoo S, Gharaghani A, Fallahi E (2017) Calcium and potassium foliar sprays affect fruit skin color, quality attributes, and mineral nutrient concentrations of 'Red Delicious' Apples. Int J Fruit Sci 17(4):358–373. https://doi.org/10.1080/15538362.2017.1318734

Swietlik D, Faust M (1984) Foliar nutrition of fruit crops. Hortic Rev 6:287–355

Szewczuk A, Komosa A, Gudarowska E (2008) Effect of soil potassium levels and different potassium fertilizer forms on yield and storability of 'Golden Delicious' apples. Acta Sci Pol Hortoru 7(2):53–59

Tahir II, Ericsson NA (2001) Effect of postharvest heating & Ca-storage on storability and quality of apple cv.'Aroma'. In: VIII International Controlled Atmosphere Research Conference, vol 600, pp 127–134

Tarabay AP, Chahine-Tsouvalakis H, Tawk ST, Nemer N, Habib W (2018) Reduction of food losses in Lebanese apple through good harvesting and postharvest practices. Ann Agric Sci 63(2):207–213

Tomala K (1996) Effects of calcium sprays on storage quality of 'Šampion' apples. Acta Hortic 448:59–66

Tripathi A, Uniyal S (2018) Effect of preharvest foliar spray of nutrients on the quality improvement of apple (Malus domestica Borkh.) in Uttarakhand. Int J Chem Sci 6(2):1910–1912

Tripathi A, Uniyal S, Pandey V (2019) Role of preharvest spray of nutrients on the shelf life improvement of apple (Malus domestica Borkh.) in Uttarakhand. J Pharmacogn Phytochem 8(1):1069–1072

Valero D, Serrano M (2010) Postharvest biology and technology for preserving fruit quality. CRC press

Van Zeebroeck M, Ramon H, De Baerdemaeker J, Nicolai B, Tijskens E (2007) Impact damage of apples during transport and handling. Postharvest Biol Technol 45:157–167

Von Bennewitz E, Cooper T, Benavides C, Losak T, Hlusek J (2011) Response of „Jonagold" apple trees to Ca, K and Mg fertilization in an andisol in southern Chile. J Soil Sci Plant Nut 11(3):71–81

Waling I, Wark WV, Houba VJG, Van der lee JJ (1989) Soil and plant analysis, a series of syllabi, part 7, plant analysis procedures, Wageningen Agriculture University, Netherland.

Yurtlu YB, Erdogan D (2005) Effect of storage time on some mechanical properties and bruise susceptibility of pears and apples. Turk J Agric For 29(6):469