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Evaluation of pre-harvest foliar calcium applications on 'Fuji' apple fruit quality during cold storage

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Abstract

In this study, calcium chloride ($CaCl_2$) and two organic calcium compounds including Calcicat® and Folical® and water (as control) were applied at four different spray programs (All-season, Early, Mid and Late season spray) at the Abhar region in Iran during 2012 and compared. 6-year-old 'Standard Fuji' trees grafted on 'MM106' rootstock were used in this study. All spray programs involved 6 biweekly sprays. Fruits harvested at commercial maturity stage and stored at commercial cold storage at $0^{\circ}C$ and RH 95%. Overall, all treated fruits received Late season $CaCl_2$ had higher Ca content, lower K/Ca and (K+Mg)/Ca ratios, and fruits treated with Folical Mid season had lower Ca, higher K/Ca and (K+Mg)/Ca ratios. Yield efficiency (No. of fruits per cm^2 trunk cross-sectional area (TCSA)) and fresh fruit weight was affected by preharvest treatments. Ca application resulted in reduced yield efficiency. SSC, TA and flesh firmness were affected by Ca application and spray programs at harvest and during 3 and 6 months storage. Control fruits in All-season spray program had highest content of SSC and fruits received $CaCl_2$ Early had lowest SSC at harvest. Folical All-season resulted in fruits with higher acidity than its control. Fruits treated with Calcicat Early had lower acidity. During 3 and 6 months cold storage, SSC increased and TA decreased. During 6 months storage, Calcicat All-season had higher SSC. Fruits received early season $CaCl_2$ had more acidity than other treatments. All-season spray of Calcicat resulted in fruits with higher firmness than other treatments. The flesh firmness during 3 and 6 months storage decreased. According to the obtained data this reduction had not specific trend among treatments.

Keywords: calcium compounds; calcium content; cold storage; fruit firmness; soluble solids concentration; spray program.
Abbreviations: SSC_soluble solids concentration, TA_titratable acidity, TCSA_trunk cross-sectional area.

Introduction

Iran, with annual production of 1.66 million tons, ranks eighth in apple production in the world (FAO 2010). However, lack of an acceptable nutritional program is lacking in the country. The role of balanced nutrition on apple fruit storability and quality has been well documented (Dris and Niskanen, 1999; Lanauskas and Kvikliene, 2006). Among the nutrients calcium is the most important affecting quality of apple and pear fruits (Fallahi et al., 1987). Calcium affects fruit senescence and quality by altering intracellular and extracellular processes and the rate of fruit softening depending on the fruit Ca status. At least 60% of the whole Ca in the plant is associated with the cell wall fraction (Fallahi et al., 2010).

The low mobility of Ca in the plant, on the other hand, poses serious problems to enhance the distribution of this element to the fruit via Ca application to the root system. Subsequently, treatment of plant aerial parts with Ca spray is recommended and applied in many fruit production areas of the world, either as routine applications to prevent the occurrence of localized Ca deficiency in the fruit or to improve fruit quality (Schlegel and Schönherr, 2002; Lötze et al., 2008; Fernández et al., 2009).

Many calcium fertilizers are suggested to fruit growers. Experimental results showed different effects of applying calcium fertilizers (Wojcik and Szwonek, 2002; Yuri et al., 2002; Lanauskas and Kvikliene, 2006). Common compounds which are used for calcium spraying are calcium chloride and calcium nitrate. Impurities in the calcium chloride can burn leaves and damage fruits and foliar calcium nitrate can cause non-bright color in red cultivars (Wooldridge and Joubert, 1997; Lanauskas and Kvikliene, 2006). Wooldridge and Joubert (1997) with comparison of organic compound Calcimax with calcium nitrate stated that Calcimax is effective as calcium nitrate in reducing the storage disorders while caused lower leaf blight than calcium nitrate.

Application time of calcium compounds also affects the spraying results. Several laboratory studies using Ca^{45} have indicated that the rate of penetration of calcium to fruit decreases with increasing the fruit age during the growing season, so that the accumulation of Ca is higher during the first phase of fruit development than the second phase of it (Schlegel and Schönherr, 2002). Some studies indicated that Ca content in fruit is higher after late season spraying rather than early and mid-season spraying (Neilsen et al., 2005; Domagała-Światkiewicz and Błaszczyk, 2009). Peryea et al. (2007), who studied six biweekly spray of $CaCl_2$ starting in mid-May (early-start), mid-June (mid-start, the normal commercial start timing), or mid-July (late-start), reported that Ca content in fruit in the control and early-start spray program did not differ. Ca content in fruit in the mid- and late start spray programs were not different, and often were higher than that of the early-start spray program. They suggested mid-season spraying program is more effective. Lötze et al. (2008) with the study of three Ca compounds including calcium nitrate, calcium acetate and Calcimax and three spraying program (start of spraying at various developmental stages, early, mid and late of season) to increase Ca content and to decrease bitter pit stated that in addition to time, compound type is also effective in Ca absorption efficiency by fruits and bitter pit disorder decreasing.

Given the above, and also tending to use organic materials as alternatives to synthetic chemical nutrients in agricultural production, the objectives of this study were (i) to evaluate the effect of two organic Ca compounds and $CaCl_2$ on quality of 'Fuji' apple fruits at harvest and during cold storage, and (ii) to compare the effectiveness of Early, Mid, Late and All-season foliar applications of different Ca solutions.

Results

Fruit mineral content after sprays

There was a significant difference concerning applied compounds and different spray programs. All treated fruits received Late season $CaCl_2$ had higher Ca content, lower K/Ca and (K+Mg)/Ca ratios. However, fruits treated with Folical Mid season had lower Ca, higher K/Ca and (K+Mg)/Ca ratios. Fruits received Late and Early season $CaCl_2$ spray had higher Ca and lower Mg, K/Ca and (K+Mg)/Ca ratios than Mid and All-season, and Late season spray treatment showed lower K content. Mid season spray with $CaCl_2$ indicated lower Ca and higher K, Mg and K/Ca and (K+Mg)/Ca ratios. About Calcicat Ca source, higher and lower Ca and K content observed at Late and All-season spray program treatment, respectively. Fruits received Early and Mid season Calcicat showed higher and lower Mg and (K+Mg)/Ca ratio, respectively. Folical Early resulted in higher Ca, K, Mg and Folical All-season revealed lower Ca content. Highest K/Ca ratio was observed in Mid season spray; however, lowest (K+Mg)/Ca was measured in Late season sprayed samples (Table 1).

Yield and fruit weight at harvest

Yield efficiency (Kg Cm^{2-} TCSA) and fresh fruit weight at harvest affected by used calcium compounds and spray programs. Trees that received Folical Late had highest yield efficiency and Calcicat All-season and $CaCl_2$ Early had lowest of it. The fruits treated with $CaCl_2$ Late had higher weight than other treatments. Overall, Late season spray program resulted in higher fruit weight than All-season, Early and Mid ones; and fruits treated with Ca solutions had higher weight compared to controls (Table 2).

Fruit quality evaluation

SSC, TA and flesh firmness were affected by Ca application and spray programs at harvest and during 3 (data not shown) and 6 months storage. According to the results, control fruits in All-season spray program had highest content of SSC and fruits received $CaCl_2$ Early had lowest SSC at harvest (Table 3). Folical All-season resulted in fruits with higher acidity than its control; whereas, $CaCl_2$ and Calcicat spray were not significantly different at harvest. Fruits treated with CaCl2 Early had lower acidity. $CaCl_2$, Calcicat and Folical Late had significant variation with their control; hence, fruits treated with Calcicat had higher TA. Folical and $CaCl_2$ had lower TA compared with their controls (Table 3). During 3 and 6 months cold storage, SSC increased and TA decreased. During 6 months storage, Calcicat Early and All-season had higher SSC and Control Mid had higher TA than other treatments (Table 4).

The 'Fuji' apple firmness as influenced by preharvest treatments was recorded in Table 3. Calcicat All-season resulted in fruits with higher firmness than other treatments and control Mid had lower firmness. The flesh firmness stored for 3 and 6 months decreased, however it was not specific trend among treatments e.g. Ca compounds or spray programs. In the case of 6 months storage, control early had higher firmness; whereas, Folical Late had lower firmness (Table 4).

Discussion

Results here showed that All-season program with the studied Ca compounds might not increase fruit Ca content rather than controls, Early and Late season. Despite Peryea et al. (2007), in our study Early and Late season had higher fruit cortical Ca content compared to Mid season. $CaCl_2$ and Calcicat Late resulted highest Ca content in fruits which is in coincidence with the findings of Neilsen et al. (2005) suggesting $CaCl_2$ spray applied Late season increased fruit Ca content higher than other programs. Folical solution spray generally did not increase fruit Ca content in comparison with control, regardless whether spray was applied Late, Mid or Early in the growing season. This might be further due to differences in the formulations of these products that may influence absorption. Despite the same Ca content of applied solutions, the absorbed calcium of them might be different throughout the growing season. Therefore, the efficacy of fruit Ca absorption should be different when Ca is applied throughout the season. Products should be applied according to the supplier recommendation in order to get the best results (Lötze et al., 2008).

Maximum Ca content in fruit at harvest occurred after multiple calcium chloride spray was applied later in the season. These results are in agreement with Neilsen et al. (2005) and Lötze et al., (2008). Although there was strong evidence that young fruits before shedding of trichomes and production of cuticular waxes having skin more permeable to Ca (Schönherr, 2001; Schlegel and Schönherr, 2002), the minimal increases in Ca content of fruit sprayed Early is an indication of the importance of fruit size to amount of calcium absorbed by a fruit (Neilsen et al., 2005).

Folical Early resulted in fruits with higher K and Mg content; and, Folical Mid showed higher K/Ca and (K+Mg)/Ca ratios, because of lowest content of Ca rather than other treatments. Calcicat and Folical Early resulted in higher K and Mg than other spray programs, whereas CaCl2 Mid had higher K and Mg compared with Early, Late ans All-seson. Calcicat Mid had lower K and Mg than Late, whereas $CaCl_2$ and Folical Mid had higher K and Mg content than those of Late. Fruits treated by $CaCl_2$ Mid had higher K/Ca and (K+Mg)/Ca ratios than Early, Late and All-season; but Calcicat Early had higher K/Ca and (K+Mg)/Ca than Late and Mid and Folical Late resulted in fruits with higher K/Ca than early and lower (K+Mg)/Ca than Early. Thus, K and Mg content and their ratios with Ca were not affected by timing of spray and dependent to Ca compounds type. These results confirmed Peryea et al. (2007) report.

Table 1. Mineral Concentration (g 100 g1- DW) in 'Fuji' Apple Fruits at Harvest.

Ca Compounds	Time of application	Ca	K	Mg	K/Ca	(K+Mg)/Ca
Control	All-season	0.14±0.005 d-g	0.95±0.02 b	0.04±0.005 d	6.82±0.6 de	7.11±0.114 d
	Early	0.12±0.017 fg	1.04±0.017 a	0.11±0.017 a	8.72±0.725 b	9.64±0.44 b
	Mid	0.12±0.005 fg	0.85±0.005 c-e	0.02±0.003 d	7.12±0.01 cde	7.3±0.3 d
	Late	0.13±0.002 efg	0.81±0.007 ef	0.02±0.005 d	6.28±1.084 ef	6.43±0.22 de
$CaCl_2$	All-season	0.15±0.004 c-g	0.79±0.006 f	0.05±0.006 c	5.30±0.094 fg	5.64±0.82 ef
	Early	0.20±0.018 ab	0.83±0.02 def	0.04±0.01 cd	4.16±0.215 hij	4.36±0.215 gh
	Mid	0.11±0.04 g	0.86±0.04 cd	0.08±0.009 b	7.83±0.11 bcd	8.56±1.06 c
	Late	0.21±0.009 a	0.74±0.009 g	0.03±0.009 cd	3.56±0.43 j	3.7±0.43 h
Calcicat	All-season	0.13±0.001 efg	0.68±0.001 h	0.04±0.001 cde	5.23±0.2 gh	5.54±0.3 ef
	Early	0.17±0.017 a-e	0.84±0.02 de	0.11±0.02 a	4.97±0.98 ghi	5.62±0.98 ef
	Mid	0.18±0.03 a-d	0.71±0.03 gh	0.04±0.002 cde	3.96±0.4 ij	4.18±0.1 gh
	Late	0.19±0.05ac	0.86±0.05 cd	0.07±0.01 b	4.55±0.6 ghi	4.92±0.6 fg
Folical	All-season	0.11±0.025 g	0.88±0.01 c	0.03+0.005 cd	8.13±0.13 bc	8.41±0.56 c
	Early	0.16±0.014 b-f	1.01 ±0.014a	0.114±0.009 a	6.33±0.7 ef	7.07±0.707 d
	Mid	0.06±0.026 h	0.82±0.018 ef	0.03±0.017 cd	13.76±0.93 a	14.26±0.93 a
	Late	0.15±0.021 c-g	0.72±0.02 g	0.03±0.021 cd	6.55±0.68 e	6.84±0.68 d

Values of similar letters, within the same column, were not significantly different according to the Duncan's multiple range test ($P \leq 0.01$).

Table 2. Fruit yield and Weight of the Studied Trees.

Ca Compounds	Time of application	No. of fruits per cm^2 Trunk cross-sectional area	Fruit weight (g)
Control	All-season	2.34±0.39ab	155.11±14.5fg
	Early	1.93±0.32b	151.48±4.55g
	Mid	3.40±0.75ab	162.57±11.76efg
	Late	3.35±1.06ab	174.35±19.12b-f
$CaCl_2$	All-season	2.58±0.61ab	167.11±7.95d-g
	Early	2.61±0.64ab	192.78±13.47ab
	Mid	3.48±0.38ab	165.26±6.04d-g
	Late	3.38±0.94ab	201.87±1.94a
Calcicat	All-season	2.17±0.31ab	167.94±5.56c-g
	Early	2.70±0.14ab	187.49±9.06abc
	Mid	2.69±0.96ab	158.95±7.35fg
	Late	2.52±0.55ab	187.36±9.38abc
Folical	All-season	2.56±0.104ab	182.39±15.07a-e
	Early	3.75±0.64ab	169.84±8.42c-g
	Mid	2.93±0.24ab	180.36±11.09b-e
	Late	3.91±1.38a	184.84±8.60a-d

Values of similar letters were not significantly different according to the Duncan's multiple range test ($P \leq 0.01$).

Table 3. Soluble Solids Concentration, Titratable Acidity and Firmness of ‘Fuji’ Apple at Commercial Harvest Were Affected by Ca Treatments.

Ca Compounds	Time of application	SSC (%Brix)	TA (g L^{-1})	Firmness (N)
Control	All-season	17.7±1.53a	4.2±0.77dg	88.3±6.76fg
	Early	16.8±1.57bcd	4.36±0.69c-f	95.5±9.65c-g
	Mid	16.9±1.01abc	4.7±0.67bc	73.86±11.54h
	Late	17.2±1.2ab	4.3±0.57def	87.06±10.5g
$CaCl_2$	All-season	16.3±0.99cd	4.7±0.56cd	90.1±15.5efg
	Early	14.6±0.8f	3.23±0.32i	97.3±11.46bf
	Mid	16.3±0.65cd	4.1±0.77efg	103.0±11.61abc
	Late	15.3±0.87ef	3.6±0.40hi	101.5±7.68bcd
Calcicat	All-season	16.4±1.65bcd	4.07±0.73efg	112.2±16.91a
	Early	16.0±1.95de	4.52±0.85c-e	101.2±17.66bcd
	Mid	15.1±1.6f	4.4±0.73c-f	94.9±18.84c-g
	Late	16.1±1.28cd	5.1±0.88ab	99.0±19.1b-e
Folical	All-season	16.9±0.76abc	5.3±0.66a	75.8±14.29h
	Early	16.8±0.84bcd	3.97±0.53fgh	103.7±7.33abc
	Mid	15.3±0.95ef	3.9±0.44fgh	92.6±14.67d-g
	Late	16.1±0.99cd	3.8±0.47gh	106.6±7.09ab

Values of similar letters, within the same column, were not significantly different according to the Duncan’s multiple range test ($P \leq 0.01$).

Table 4. Soluble Solids Concentration, Titratable Acidity and Firmness of ‘Fuji’ Apple During 6 Months Storage at 0ºC Were Affected by Ca Treatments.

Ca Compounds	Time of application	SSC (%Brix)	TA (g L^{-1})	Firmness (N)
Control	All-season	17.9±1.6abc	2.1±0.55a-d	71.4±7.7abc
	Early	17.1±1.01b-e	1.5±0.23e	76.4±7.11a
	Mid	17.3±0.91b-e	2.3±0.23a	68.5±4.82a-d
	Late	17.6±1.02a-d	1.9±0.21a-e	63.3±7.18cd
$CaCl_2$	All-season	16.9±0.69cde	2.1±0.18abc	65.5±1.03bcd
	Early	18.1±0.43ab	2.06±0.16a-d	66.8±7.57a-d
	Mid	16.3±1.56e	1.8±0.37b-e	66.7±6.99a-d
	Late	17.1±1.06b-e	1.9±0.23a-e	68.7±4.75a-d
Calcicat	All-season	18.4±0.84a	1.9±0.2a-e	73.5±7.02ab
	Early	18.4±0.78a	1.9±0.36a-e	66.0±9.07bcd
	Mid	15.3±1.61f	2.2±0.7ab	66.3±9.0bcd
	Late	17.8±0.99a-d	2.2±0.44ab	72.1±6.93abc
Folical	All-season	17.2±1.07b-e	2.1±0.56abc	69.0±5.31a-d
	Early	17.1±0.63b-e	1.9±0.16a-e	65.5±5.33bcd
	Mid	16.7±1.91de	1.6±0.17de	71.7±10.9a-c
	Late	16.8±0.73c-e	1.6±0.33c-e	59.1±9.65d

Values of similar letters were not significantly different according to the Duncan’s multiple range test ($P \leq 0.01$).

yield efficiency varied between 3.91-1.93 (No. of fruits per cm^2 TCSA). In agreement with Rosenberger et al. (2004) results, yield efficiency and fruit weight were affected by Ca foliar application. Overall Ca application in each spray program resulted in reduced yield efficiency. Different results have been reported regarding the effect of calcium on fruit size (Rosenberger et al., 2004, Nielsen et al., 2005). In this investigation application of Ca fertilizers resulted in fruits with higher weight; which are in coincidence with Kadir (2005).

There are plenty of information on the effect of calcium on fruit firmness, SSC and TA (Dris and Niskanen, 1996; Yuri et al., 2002). Overall, our data approved with Neilsen et al. (2005) results that reported fruit TA was affected by Calcium treatments. They expressed in first year, fruit acidity was reduced at harvest for fruit receiving Early and Mid season $CaCl_2$ or $CaCo_3$; and in second year, $CaCl_2$ sprayed fruit showed reduced acidity compared to unsprayed ones. Despite of their results, in our study, fruit received $CaCl_2$ Early, Mid and Late, and Folical Mid and Late showed lower acidity.

There are conflicting reports as to the relationship between calcium content and apple fruit firmness. According to the some study fruit firmness at harvest to increase slightly with increased flesh Ca content whereas in some other studies the firmness of apples does not appear to be influenced by preharvest spray of CaCl2 or other commercially available Ca mixtures (Bramlage et al., 1979, 1985). As the data revealed here, the obtained data approved with that found by Dris and Niskanen (1999) who indicated that foliar Ca application significantly increased the fruit firmness. The same trend was obtained by other studies such as Neilsen et al. (2005) who found that treatment with $CaCl_2$ effectively increased fruit firmness. Calcium serves as an intermolecular binding agent that stabilizes pectin-protein complexes of the middle lamella. Calcium also plays an important role in the cell membrane by inducing rigidification at the membrane surface of apple fruit tissue (Fallahi et al., 1997). The fruit firmness decreased during cold storage. In fact, storage at low temperature, due to the decomposition of the middle membrane, results in cell separation and fruit firmness reduction (Chardonnet et al., 2003). Calcium treatment had no effect on the reduction of fruit firmness, with the exception of Folical All-season which showed less decline compared to the control.

Materials and Methods

Plant materials

This study was conducted at the Haydari's Orcahrd, Abhar, Iran during 2012. 'Standard Fuji' trees on 'MM106' rootstock were planted at 2.5 x 4 m spacing in 2006. A randomized block design with 3 replications and 4 tree plots was used.

Ca compounds and spray program

In this study, two organic Ca compounds namely Calcicat® including 20.5% of calcium as CaO, other elements such as nitrogen, magnesium, iron, manganese and zinc, and trace amounts of organic acids and Folical® including 17% calcium, organic acids and plant system amplifiers and calcium chloride as mineral compound with the control (water) in four different spray programs were compared. 5 g L^{-1} $CaCl_2$ solution was used (Peryea et al., 2007) and the organic compounds were equal with $CaCl_2$ regarding of Ca content. The four different spray programs were: a) Early season (10-15 days after full bloom (DAFB)) involving 6 biweekly spray starting late May and Late-July, b) Mid-season (35 DAFB) involving 6 biweekly spray starting early June and ending Mid-August, c) Late season (60 DAFB) involving 6 biweekly spray starting late June and ending late September and d) All-season (10-15 DAFB) late May and ending late September. The $CaCl_2$ solution was prepared in a trailer-mounted 100-L sprayer towed behind a tractor. The experimental trees were sprayed to drip.

Harvest and storage condition

Harvest samples consisting of 60 randomly selected fruit per plot were collected on late September. The sample fruits were randomly collected from the outside of the middle third of the canopy from all treatment trees. The fruit remaining on the tree after the harvest samples had been removed were counted to determine total crop load. Trunk diameters were measured at same height above the soil line to allow calculation of No. of fruits per cm^2 trunk cross-sectional area (TCSA). A randomly sample of 20 fruits transferred to laboratory and 40 fruits stored in commercial cold storage at $0^{\circ}C$, RH 95% located in Karaj region, Alborz province, for 3 or 6 months.

Fruit quality evaluation

At harvest and after 7 days ripening at room temperature following 3 and 6 months storage at $0^{\circ}C$, a randomly selected 10 apple subsample from all plots was evaluated for flesh firmness, titratable acidity (TA), and soluble solids concentration (SSC). Flesh firmness was measured at two opposite points on the fruit equator (sunny and shady sides) using a penetrometer with an 11.1 mm diameter head and averaged. SSC was determined with a refractometer and TA was measured by titration of juice with 0.1 M NaOH to an 8.1 pH end point.

Mineral element determination

Samples were analyzed for flesh mineral content at harvest. A random sample of 10 fruit was also selected at harvest from each treatment and replicate and rinsed with HCl 0.1 M and then washed with deionized water and air dried. Fruits were cut longitudinally and small wedges from 1cm below the skin were sampled. Mineral analyses were performed at the nutrient analysis laboratory. Ca and Mg content were determined by atomic absorption spectroscopy and K by flame emission (Waling et al., 1989). All nutrient content values were expressed as gram per 100 gram dry mass basis.

Statistical analysis

Analysis of variance was performed on all fruit data as a split plot design. All statistical analyses were undertaken using the general linear model (GLM) procedure of the SAS version 9.0. The Duncan' multiple range test ($P \leq 0.01$) was used to evaluate differences between treatments.

Conclusion

The cumulative results of this research indicate the efficacy of various calcium containing solutions to increase fruit calcium content depend on formulation of the product and timing of applications. Because of Ca absorbance dependent to formulation of Ca compounds and climatic conditions such as temperature and humidity, this study should be performed in the specific climatic condition to delineate best spray program. In our region, Early and Late season spray led to higher Ca content. $CaCl_2$ and Calcicat Late resulted in fruits with the highest Ca content.

References

Bramlage W, Drake M, Baker J (1979) Changes in calcium level in apple cortex tissue shortly before harvest and during postharvest storage. Commun Soil Sci Plant Anal. 10: 417-426.

Bramlage W, Drake M, Weis S (1985) Comparisons of calcium chloride, calcium phosphate, and a calcium chelate as foliar sprays for 'McIntosh' apple trees. J Amer Soc Hort Sci. 110: 786-789.

Chardonnet CO, Charron CS, Sams CE, Conway WS (2003) Chemical changes in the cortical tissue and cell wall of calcium-infiltrated 'Golden Delicious' apple during storage. Postharvest Biol Technol. 28: 97-111.

Domagala-Swiatkiewicz I, Blaszczyk J (2009) Effect of calcium nitrate spraying on mineral contents and storability of 'Elise' apples. Pol J Environ Stud. 18: 971-976.

Dris R, Niskanen R (1996) Effect of calcium on the storage quality of apples grown in Finland. Acta Hort. 448: 323-328.

Dris R, Niskanen R (1999) Calcium chloride sprays decrease physiological disorders following long-term cold storage of apple. Plant Food Hum Nutr. 54: 159-171.

Fallahi E, Conway WS, Hickey KD, Sams CE (1997) The role of calcium and nitrogen in postharvest quality and disease resistance of apples. HortScience. 32: 831-835.

Fallahi E, Fallahi B, Nielsen GH, Nielsen D, Peryea FJ (2010) Effects of Mineral Nutrition on Fruit Quality and Nutritional Disorders in Apples. Acta Hort. 868: 49-59.

Fallahi E, Righetti TL, Wernz JG (1987) Effects of dip and vacuum infiltrations of various inorganic chemicals on post-harvest quality of apple. Commun Soil Sci Plant Anal. 18: 1017-1029.

Fernández V, Díaz A, Blanco Á, Val J (2009) Surface application of calcium-containing gels to improve quality of late maturing peach cultivars. J Sci Food Agric. 89: 2323-2330.

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

Lanauskas J, Kvikliene N (2006) Effect of calcium foliar application on some fruit quality characteristics of ‘Sinap Orlovskij’ apple. Agron Res. 4: 31-36.

Lötze E, Joubert J, Therson K (2008) Evaluating pre-harvest foliar calcium applications to increase fruit calcium and reduce bitter pit in ‘Golden Delicious’ apples. Sci Hort. 116: 299-304.

Neilsen G, Neilsen D, Dong S, Toivonen P, Peryea F (2005) Application of $CaCl_2$ sprays earlier in the season may reduce bitter pit incidence in'Braeburn'apple. HortScience. 40: 1850-1853.

Peryea FJ, Neilsen GH, Faubion D (2007) Start-timing for calcium chloride spray programs influences fruit calcium and bitter pit in ‘Braeburn’and ‘Honeycrisp’apples. J Plant Nutr. 30: 1213-1227.

Rosenberger D, Schupp J, Hoying S, Cheng L, Watkinz C (2004) Controlling Bitter Pit inHoneycrisp'Apples. HortTechnology. 14: 342-349.

Schlegel TK, Schönherr J (2002) Stage of development affects penetration of calcium chloride into apple fruits. J Plant Nutr Soil Sci. 165: 738-745.

Schönherr J (2001) Cuticular penetration of calcium salts: effects of humidity, anions, and adjuvants. J. Plant Nutr. Soil Sci 164: 225-231.

Waling I, Van Vark W, Houba V, JJ VDL (1989) Soil and plant analysis, a series of syllabi. Part 7, plant analysis procedure. Wageningen Agriculture University.

Wojcik P, Szwonek E (2002) The efficiency of different foliar-applied calcium materials in improving apple quality. Acta Hort. 594: 563-567.

Wooldridge J, Joubert M (1997) Effect of Calcimax on fruit quality parameters in apples and plums. Decid Fruit Grow. 47: 30-34.

Yuri J, Retamales J, Moggia C, Vàsquez J (2002) Bitter pit control in apples cv. Braeburn through foliar sprays of different calcium sources. Acta Hort. 453-460.