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Effect of spraying with calcium chloride at different water rates on 'Jonagold' apple calcium concentration

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Summary

The aim of the study was to examine the effect of calcium chloride ($CaCl_2$) spraying at different rates of water on apple (*Malus domestica* Borkh.) calcium concentration. The examination was carried out in 1997-1998 on 'Jonagold' apple trees grafted on M.26 rootstock and planted in 1990 on sandy-loam soil at a distance of 4 x 2.5 m.The trees were trained as a spindle at 2.4 m and 2 m of height and canopy width, respectively. In the experiment apple trees were sprayed with $CaCl_2$ at a rate of 7 kg ha^{-1} using 250, 500, 1000 and 1500 L of water volumes which gives: 2.8, 1.4, 0.7 and 0.5% $CaCl_2$ solutions, respectively. Sprays with $CaCl_2$ solutions were applied 6, 4 and 2 weeks before commercial fruit harvest. The trees unsprayed with Ca served as a control.

The study showed that sprays with $CaCl_2$ at all studied water volumes had not effect on leaf and fruit damages. Regardless of the applied water rates, apples from the middle and the bottom of the canopy had higher calcium concentrations as a result of $CaCl_2$ sprays whereas this treatment had not effect on fruit calcium concentration from the top of the canopy. However, the laboratory study showed that 'Jonagold' apples from the canopy top had ability to take up exogenous calcium. It was found that efficacy of $CaCl_2$ sprays at studied water rates in increasing fruit calcium concentration was similar. The study showed as well that young 'Jonagold' fruitlets took up clearly less exogenous calcium compared to mature fruit which suggests that sprays of this cultivar with calcium salts should be applied mainly at late apple development stages.

Key words: calcium spraying, different water rates, apple calcium concentration

INTRODUCTION

Apple mineral composition plays an important role in their quality (Marcelle, 1995). Particularly, apple flesh calcium (Ca) concentration strongly affects on their quality. Namely, apples with low Ca concentrations are sensitive to many diseases and physiological disorders, have poor storage ability and a short period of shelf life (Conway, 1982;

Poovaiah, 1986; Sharples and Johnson, 1977; Wilkinson and Fidler, 1973). Apple fruit with low Ca concentrations has been causing the great economic losses to growers (Marcelle, 1995).

It has been proved that many soil-and biological-factors, such as: soil pH, Mg and K contents in soil solution, soil moisture, rootstock, cultivar, crop load, position of apples within the tree canopy, apple size, etc. have the effect on the uptake and/or the accumulation of Ca into apple tissues (Conway et al., 1995; Ferguson and Watkins, 1992; Shear, 1975; Tomala and Dilley, 1990; Wiersum, 1966; Vang-Petersen, 1980). However, many authors state that Ca deficiency in apple flesh tissues is related mainly to specific Ca movement within plant (Faust et al., 1971; Ferguson et al., 1979; Shear, 1975; Bangerth, 1979). As outlined by these authors, leaf Ca applications are necessary to produce apples with high Ca concentrations. However, the efficacy of Ca sprays in increasing apple tissue Ca concentration depends on many factors, such as: cultivar, a kind and rate of Ca fertiliser and weather conditions during and after period of Ca spraying (Glenn and Poovaiah, 1985; Glenn et al., 1985; Roy et al., 1996; Van Goor, 1973; Yuen, 1993). The efficacy of Ca sprays in increasing fruit Ca concentration may be also related to a rate of water used. Therefore, we attempted to examine the effect of a water rate used in $CaCl_2$ spray on apple Ca concentration.

MATERIALS AND METHODS

Experiment 1.

The aim of this study was to examine the ability of 'Jonagold' apples (*Malus domestica* Borkh.) from different parts of the tree canopy to take up exogenous Ca. Cv. Jonagold was selected to this experiment because its fruits are particularly sensitive to many physiological disorders related to Ca deficiency. Fruits were harvested from seven-year-old apple trees growing in Dąbrowice Experimental Orchard of the Research Institute of Pomology and Floriculture in Skierniewice. The trees were planted on sandy-loam soil at a distance of 4 x 2.5 m in north-south oriented rows and were trained as a spindle. The protection against pathogens and pests, fertilisation and other orchard managements were applied according to standard recommendations for plant production. Apple trees were not sprayed with Ca solutions. Apple fruit to 0.8 m (bottom), from 0.9 to 1.6 m (middle) and from 1.7 to 2.4 m (top) of the canopy height were separately sampled. Ten fruits from ten trees from each part of the canopy were collected when they had 24-27 mm (first term of harvest) and 75-80 mm (second term of harvest) of diameter. Fruits from first term of harvest were immersed into: 0.55, 1.10, 2.20 and 3.40-L deionized water volumes with 15.8 g $CaCl_2$ whereas fruit from the second one into: 1.60, 3.20, 6.40 and 10.0-L water volumes with 46g $CaCl_2$ which in both cases gives: 2.8, 1.4, 0.7 and 0.5% $CaCl_2$ solutions, respectively. Apples from both harvest terms were dipped 2 minutes and then were taken into plastic bags and held during 14 days at 18-20^{0}C. Apples undipped into $CaCl_2$ solutions served as a control. The experiment was designed with three replicates.

In experiment apple tissue Ca concentration was determined immediately after removing fruits from the bags. Fruit were rinsed in double-deionized water and gently blotted dry by soft tissue paper. The seeds and stems were removed and then 2 quarters of apple were cut out from two opposite sides. The fruit samples were dried at 65°C for 72h, ground and digested in 9:1 (v/v) diacid mixture of HNO_3 and $HClO_4$. Calcium was determined by an inductively-coupled plasma spectrometer (ICP, Thermo Jarrell).

Experiment 2.

The aim of this study was to examine the effect of $CaCl_2$ sprays at different water volumes on apple Ca concentration. The study was carried out in 1997-1998 in Dąbrowice Experimental Orchard on 'Jonagold' apple trees grafted on M.26 rootstock and planted in 1990 on sandy-loam soil at a distance of 4 × 2.5m (1000 trees per ha). The trees were trained as a spindle. In order to form the tree canopy as a spindle, winter and summer prunings were performed annually. During period of the study, the height and the width of the tree canopy were 2.4 m and 2 m, respectively. The experiment was designed using a randomised complete block design with three replicates. Each experimental plot contained ten trees. Between the experimental plots there were two trees serving as protective belts. Five experimental treatments were applied:

(i) sprays with $CaCl_2$ at a rate of 7 kg per ha using 250 L of water (2.8% $CaCl_2$ solution).
(ii) sprays with $CaCl_2$ at a rate of 7 kg per ha using 500 L of water (1.4% $CaCl_2$ solution).
(iii) sprays with $CaCl_2$ at a rate of 7 kg per ha using 1000 L of water (0.7% $CaCl_2$ solution).
(iv) sprays with $CaCl_2$ at a rate of 7 kg per ha using 1500 L of water (0.5% $CaCl_2$ solution).
(v) control - trees unsprayed with $CaCl_2$ solutions.

In all Ca treatments, $CaCl_2$ sprays were applied 6, 4 and 2 weeks before fruit harvest. Sprays with $CaCl_2$ solutions were done by SEPIA sprayer with directed airstream. In order to reach the adequate rates of water per ha different pressures and types of nozzles were used (Table1). Travel speed of the sprayer during each spraying was 4 km h^{-1}. All $CaCl_2$ sprays were done in the morning when the tree leaves were dry.

Table 1

Applied pressures and nozzles (ATR ALBUZ) $CaCl_2$ solution sprays at different water rates

Parameter	Rate of water [L ha^{-1}]			
	250	500	1000	1500
Pressure [kPa]	400-450	1000-1050	1200-1250	1450-1500
Type of nozzle	yellow	orange	green	blue

The following measurements and observations were carried out during the experiment:

1. Apple flesh Ca concentration was estimated in fruit from the bottom, the middle and the top of the tree canopy located to 0.8 m, from 0.9 to 1.6 m and from 1.7 to 2.4 m

of the canopy height, respectively. Three apples at harvest time from each part of the canopy were randomly sampled from each tree. Preparation of the fruit samples and determination of Ca concentration were done in the identical way as in experiment 1.

2. Calcium content on fruit skin surface was determined only after last spraying with $CaCl_2$ solutions, through placing $8cm^2$-blotting-paper slips on fruit surface. On each tree three blotting-papers were placed on apple surface from the top, the middle and the bottom of the tree canopy, separately. Immediately after spray with $CaCl_2$, the slips of blotting-papers from each part of the canopy were removed, taken into 25ml-plastic vessels. To each vessel 20 ml of distilled water was added. The vessels were strongly shacked and then the blotting-papers were removed. The solutions obtained in this way were used to determine Ca concentrations.
3. Russeting apples was determined after fruit harvest based on 20 kg-fruit sample from each plot. Russeting fruit was estimated according to following scale:
   1. Fruit without russeting
   2. Fruit with russeting to 25% of skin surface
   3. Fruit with russeting on 26-50% of skin surface
   4. Fruit with russeting on 51-75% of apple skin surface
   5. Fruit with russeting above 76% of skin surface
4. Leaf damages were determined five days after last spray with $CaCl_2$ based on 30 leaves from each plot sampled from one-year-old shoots at the central zone of the canopy. Leaf damages were estimated based on following scale: 0-no leaf scorch; 1-scorch at leaf tips; 2- scorch on leaf edges; 3-scorch apparent on more than 50% of the leaf surface.

In the experiment 1 and 2 the differences between mean values of treatments were evaluated by Duncan's multiple range test, at the level of significancy $P \leq 0.05$. Data of russeting apple were transformed according to $y = \arcsin\sqrt{x}$.

RESULTS

Experiment 1.

Immersion of 'Jonagold' apples generally resulted in no fruit skin damages. Apples immersed in $CaCl_2$ solutions from all zones of the canopy from both harvest terms had higher Ca concentrations in flesh tissues compared to those of control plots (Table 2). However, the increase of fruit Ca concentration was related to $CaCl_2$ solution concentration. With increasing water volumes (decrease of $CaCl_2$ solution concentration) it was observed the decrease of exogenous Ca uptake by fruit; although this effect was not found in some cases. Namely, Ca concentrations in fruit dipped in 0.5 and 0.7% $CaCl_2$ solutions from the top and the middle of the canopy from both harvest terms did not differ significantly. Also, Ca content in apple flesh tissues from the top of the canopy from second harvest term was not affected by $CaCl_2$ solution concentration. On average for all $CaCl_2$ solution concentrations, the increases of fruit Ca contents from first and second harvest term were: 10 and 31% for fruit from the top, 7 and 28% for fruit from the middle and 15 and 34% for fruit from the bottom of the tree canopy, respectively. For all $CaCl_2$ solution concentrations and terms of fruit harvest, the increases of fruit flesh Ca content from the top, the middle and the bottom of the tree canopy were 20, 17 and 24%, respectively.

Experiment 2.

Table 2
Effect of immersion of 'Jonagold' apples in different $CaCl_2$ solution
on fruit Ca concentration

Concentration $CaCl_2$ solution [%]	Fruit calcium concentratoin [mg Ca kg^{-1} DM]					
	Part of tree canopy					
	Top		Middle		Bottom	
	Term 1.	Term 2.	Term 1.	Term 2.	Term 1.	Term 2.
0.5	2275b	233b	2212b	207b	2511b	252b
0.7	2246b	223b	2254b	209b	2601c	293c
1.4	2366c	229b	2355c	247c	2800d	325d
2.8	2553d	230b	2478d	268d	2904e	352e
Control	2141a	175a	2175a	181a	2352a	228a

Means followed by the letter within the column do not differ at $P \leq 0.05$ by Duncan test

Table 3
Effect of spraying with $CaCl_2$ at different water volumes on 'Jonagold'
apple calcium concentration

Water volume [L ha^{-1}]	Fruit calcium concentratoin [mg Ca kg^{-1} DM]					
	1997			1998		
	Part of tree canopy			Part of tree canopy		
	Top	Middle	Bottom	Top	Middle	Bottom
1500	147a	238b	263b	156a	272b	261b
1000	147a	244b	259b	147a	261b	256b
500	149a	237b	258b	147a	261b	256b
250	149a	243b	249b	147a	264b	261b
Control	143a	189a	204a	142a	203a	216a

Means followed by the same letter within the column do not differ at $P \leq 0.05$ by Duncan test

In both years of the study, sprays with $CaCl_2$ at studied water rates had similar effect on 'Jonagold' apple Ca concentration (Table 3). Apples from the middle and the bottom of the canopy sprayed with $CaCl_2$ had higher fruit tissue Ca concentrations compared to those of control plots; however apple Ca concentration was not affected by water rates applied. In the case of apples from the canopy top, sprays with $CaCl_2$ solutions had not effect on fruit Ca concentration.

In both years of the examination, amounts of Ca absorbed by the blotting-papers as a result of $CaCl_2$ sprays were similar (Table 4). Generally, Ca contents in the blotting-papers from all parts of the tree canopy were higher as a result of $CaCl_2$ sprays compared to those of control plots. Calcium contents in the blotting-papers from the middle and the bottom of the canopy were not affected by applied water rates. In the case of apples from the top of the tree canopy, Ca contents in the blotting-papers were related to water rates used. Namely, with increasing water rates increased Ca contents in the blotting-papers; although Ca contents in the case of applying 1500 and 1000 L of water did not differ.

Table 4

Effect of sprays with $CaCl_2$ at different water volumes on 'Jonagold' apple surface

Water volume [L ha^{-1}]	Fruit surface calcium content [µg Ca cm^2]					
	1997			1998		
	Part of tree canopy			Part of tree canopy		
	Top	Middle	Bottom	Top	Middle	Bottom
1500	550d	720b	690b	510d	690b	750b
1000	540d	700b	680b	530d	680b	720b
500	450c	700b	670b	430c	670b	730b
250	240b	700b	690b	270b	670b	710b
Control	10a	20a	20a	40a	20a	20a

Means followed by the same letter within the column do not differ at $P \leq 0.05$ by Duncan test

In both years of the experiment, $CaCl_2$ sprays had not effect on russeting 'Jonagold' apple. Percentage of apples with russeting above 26% of skin surface ranged from 3.0 to 6.5 in 1997 and from 2.3 to 4.4 in 1998. Also, leaf damages were not affected by sprays with $CaCl_2$ solutions and averaged 0.2 and 0.3 in 1997 and 1998, respectively.

DISCUSSION

The major barrier to penetration of exogenous Ca into the apple flesh tissues is the cuticle (Norris and Bukovac, 1968). Transport of solutes across plant cuticles occurs either through natural pores, such as: stomata, lenticels and cracks or by penetration of the epicuticular wax and transport through the largely hydrophobic matrix of the cuticle (Price, 1982; Schönherr, 1976). In the first experiment it was found that on average for all parts of the canopy and $CaCl_2$ solution concentrations, the immersion of 'Jonagold' apples from first and second harvest term resulted in the increase of fruit tissue Ca concentrations by 11 and 31%, respectively. Those results indicate that 'Jonagold' fruitlets had the lower ability to take up exogenous Ca compared to mature fruit. Also, Lewis and Martin (1973), Stahley (1986) and Van Goor (1973) showed the changes in Ca^{2+} penetration into the apple flesh at different stages of their growth. According to the studies of those authors the penetration of Ca into apple flesh tissues was greatest when Ca^{2+} was applied on the surface of mature fruit. High ability of mature apples to take up exogenous Ca could result from increasing number of open lenticels and their permeability and as well from forming microcracks and flaws in the cuticle during fruit development (Harker and Ferguson, 1988; Martin and Lewis 1967). However, there are some evidences pointed out than young apples took up more exogenous Ca that mature fruit (Michalczuk and Kubik,1984; Wienecke, 1968). According to those authors intensive uptake of exogenous Ca by young apples was probably due to the high density of open lenticels on skin surface unit and thin cuticle. The diverse study results on ability to take up exogenous Ca by apples at various status of their development may result from different environmental conditions and specificity of cultivar as suggested by Harker and Ferguson (1988).

The blushed apple skin surface had less intensive network of cracking than green fruit skin which suggests that apples from the tree canopy top with the intensive blush have a poor ability to take up exogenous Ca (Wójcik et al., 1997). In the first experiment it was found that on average for all $CaCl_2$ solution concentrations and both fruit harvest terms, apple Ca concentrations from the top, the middle and the bottom of the tree canopy were higher by 20, 17 and 24%, respectively. It indicates that apples from the canopy top took up slightly less exogenous Ca than fruits from the bottom of the tree canopy. According to Miller (1982) the differences in fine structure of apple skin surface between fruit from the top and the inside of the tree canopy are induced by temperature and/or light. In our experiment as a result of dormant and summer pruning, the tree canopies were „loose" which could reduce the differences of temperatures and light in studied zones of the canopy. Thus, probably from this reason 'Jonagold' apples from the top did not differ distinctly in uptaking exogenous Ca compared to those of the middle and the bottom of the canopy.

Uptake of Ca ions by plants is passive as shown by Ferguson and Clarkson (1976) which means that Ca^{2+} diffuse from a higher to a lower concentration ('downhill' transport). Thus, the movement of exogenous Ca into apple flesh tissues is related at least partly to the amounts of Ca ions on fruit skin surface. In the first experiment 'Jonagold' apple Ca concentrations generally corresponded with $CaCl_2$ solution concentrations with exception of apples from the canopy top sampled in second term. A lack of the differences obtained in Ca concentrations in apples from the canopy top from second harvest term between fruit dipped into various $CaCl_2$ solution concentrations is difficult to explain.

In the second examination it was found that 'Jonagold' apple Ca concentration sprayed with $CaCl_2$ solutions was not affected by applied water rate. Also, the study of Cross and Berrie (1990) showed that sprays with $CaCl_2$ at a rate of 8 kg ha^{-1} using 50, 100 and 500 L had similar effect on increase of 'Cox's Orange Pippin' apple Ca concentration; however lowering rates of $CaCl_2$ in the case of applied 50 and 100 L of water volumes to reach 1.6% solutions resulted in less increase of apple Ca concentrations compared to $CaCl_2$ sprays at a rate of 8 kg ha^{-1} using 500 L of water volumes (1.6% solution). Based on those results, authors concluded that critical factor affecting an increase of apple Ca concentration as a result of Ca sprays is Ca rate applied. In our experiment fruit Ca concentrations from the middle and the bottom of the tree canopy corresponded with Ca contents in the blotting-papers on fruit skin surface. Thus, in these cases the increase of fruit Ca concentration was related to amount of Ca delivered on apple skin surface from $CaCl_2$ sprays. However, in the case of apples from the tree canopy top, Ca contents in the blotting-papers increased with increasing rates of water. The lower amounts of Ca absorbed by the blotting-paper in the canopy top as a result of spraying with $CaCl_2$ at 500 and 250 L of water compared to 1000 and 1500 L of water volumes could result from solution drift as outlined by Herrington et al. (1981). It is possible because it is well proved that spraying at low solution rates, increases the risk of drift of their drops (Yates et al., 1983 and Yates et al. 1985). Regardless of the amounts of Ca absorbed by the blotting-papers on the apple surface from the canopy top as a result of $CaCl_2$ sprays, fruit from this canopy zone did not differ Ca concentrations compared to control ones. Taking into consideration that 'Jonagold' apples from the canopy top had ability to take up exogenous Ca which was proved in the first experiment, it seems that a lack of effect of $CaCl_2$ sprays on fruit Ca concentration probably was due to intensive evaporation from apple skin surface. It is possible because the evaporation from apple surface from the tree canopy top is higher compared to fruit from the canopy inside.

CONCLUSIONS

1. Sprays with $CaCl_2$ at a rate of 7kg ha^{-1} using 250, 500, 1000 and 1500 L of water volumes increased apple Ca concentrations from the middle and the bottom of the canopy but had not effect on fruit Ca concentration from the canopy top.
2. Apple Ca concentrations within tree canopy as a result of $CaCl_2$ sprays were not affected by applied water rates.
3. Ability of 'Jonagold' apples picked off trees to take up exogenous Ca was related to fruit development stage. Young fruitlets took up less exogenous Ca compared to mature apples.

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Wpływ opryskiwania chlorkiem wapnia w zróżnicowanych objętościach wody na zawartość wapnia w jabłkach odmiany Jonagold

Streszczenie

Celem tego doświadczenia było określenie wpływu opryskiwania jabłoni (*Malus domestica* Borkh.) chlorkiem wapnia ($CaCl_2$) w różnych objętościach wody na zawartość wapnia w owocach. Doświadczenie zostało przeprowadzone w latach 1997-1998 na jabłoniach odmiany Jonagold szczepionych na podkłace M26 i posadzonych w 1990 roku na glebie piaszczysto-gliniastej w roztawie 4 × 2,5 m. Drzewa prowadzone były w formie wrzecionowej o wysokości korony 2,4 m i jej szerokości 2 m. Jabłonie opryskiwano $CaCl_2$ w dawce 7 kg ha $^{-1}$ stosując 250, 500, 1000 i 1500 L wody, co daje następujące stężenia roztworu: 2,8; 1,4; 0,7 i 0,5%. Opryskiwania wykonywane były 6, 4 i 2 tygodnie przed zbiorem owoców. Drzewa nieopryskiwane wapniem stanowiły kontrolę.

Wyniki badań wykazały, że opryskiwania $CaCl_2$ w badanych objętościach wody nie miały wpływu na uszkodzenia liści oraz owoców. Pod wpływem opryskiwania $CaCl_2$, niezależnie od zastosowanej dawki wody, jabłka ze środka i podstawy korony miały wyższą koncentrację wapnia niż owoce z drzew kontrolnych. Jednakże opryskiwania $CaCl_2$ nie miały wpływu na zawartość wapnia w jabłkach pochodzących z wierzchołka korony. Badania laboratoryjne wykazały jednak, że jabłka z wierzchołka korony drzew miały zdolność do pobierania egzogennego wapnia. W badaniach stwierdzono także, że skuteczność opryskiwań $CaCl_2$ w zwiększaniu koncentracji wapnia w jabłkach nie była uzależniona od stosowanej dawki wody. Wykazano także, że zawiązki odmiany Jonagold zbierane z drzew pobierały mniej wapnia w porównaniu do owoców zbieranych w momecie ich dojrzałości zbiorczej, co sugeruje, że opryskiwania tej odmiany roztworami wapnia powinny być wykonywane w późniejszych fazach wzrostu owoców.