The effect of calcium foliar fertilizers on cv. Ligol apples

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ABSTRACT

The effects of calcium fertilizers on cv. Ligol apples were studied in the experiment conducted at the Lithuanian Institute of Horticulture in 2007–2009. Fertilizers were applied four or eight times from June to September on the 8^{th}–9^{th} leaf of apple trees on P 22 rootstock. Calcium nitrate or liquid calcium fertilizers were used. The results differed over the years of experiment. During the first year, four applications of liquid calcium fertilizers significantly reduced the Mg/Ca ratio in fruit, whereas in 2008 the tendency of decrease in the ratios of K/Ca and Mg/Ca at both fertilizers was observed. The bitter pit incidence rate on stored apples of the 2007 yield was 1.5–3.0%. The eight applications of liquid calcium fertilizers significantly reduced the incidence of bitter pit after storage. In 2008, higher fruit calcium content and lower ratios of N/Ca, K/Ca, and Mg/Ca were detected. Moreover, these apples were not affected by bitter pit. The worse fruit quality of the 2007 yield could be linked to the abundant rainfall during 2007 vegetation season. However, the application of fertilizers had a positive effect on natural weight loss and fruit flesh firmness after storage.

Keywords: bitter pit; flesh firmness; weight loss; storage

The chemical composition of fruit influences fruit quality traits. Abundant research emphasizes the importance of calcium in apples (Jackson 2003). Such properties as resistance to physiological disorders and quality of the fruit after storage are related to the fruit calcium content. Usually apple trees accumulate enough calcium, whereas fruit may be calcium-deficient as the xylem vasculature in fruit undergoes a progressive dysfunction during the season (Drazeta et al. 2001).

Nutrient content of apple fruit depends on environmental, genetic, and orchard management factors. The investigation of calcium effect on apples of commercially grown cultivars is a common practice in many countries (Jackson 2003). The quality of apple fruit depends on the absolute amount of calcium, and on the ratio of calcium to other elements. Lower N/Ca (nitrogen to calcium), K/Ca (potassium to calcium), or Mg/Ca (magnesium to calcium) ratios usually result in better fruit storage and less susceptibility to bitter pit, in addition to other physiological disorders (Casero et al. 2009, Guerra and Casquero 2010). Calcium fertilizers are used to increase fruit calcium content. They are applied from early fruit development stages to postharvest period, since there is no consensus on optimal application time (Conway et al. 2002, Peryea et al. 2007, Wójcik et al. 2009). There is abundant choice of calcium fertilizers, but calcium nitrate or chloride are the most common.

The objective of this research is to investigate the effect of calcium fertilizer sprays on chemical composition of cv. Ligol apple fruit, and to evaluate quality parameters and storage properties of fruit.

MATERIAL AND METHODS

The experiment was carried out at the Lithuanian Institute of Horticulture (55°60'N; 23°48'E) in 2007–

Supported by the Lithuanian Research Centre for Agriculture and Forestry.

2008. Apple trees of the Ligol cultivar on rootstock P 22 were sprayed with calcium nitrate (15.5% N, 18.9% Ca), or liquid calcium fertilizers containing 8.0% N, 10.5% Ca and 0.3% Mg. Calcium nitrate was applied eight times at the rate of 8.5 kg/ha Ca. Liquid calcium fertilizers were used eight times at the rate 8.5 kg/ha Ca, or four times at the rate 4.6 kg/ha Ca. The amount of water used was 1000 L/ha. The fertilizers were applied from the second half of June to the end of September with increasing concentration of calcium nitrate (from 0.3% to 0.8%). Intervals between applications were about two weeks and about a month in eight-time and four-time treatment, respectively.

The apple tree orchard was in 8^{th}–9^{th} leaf with the planting scheme 3 × 0.85 m. The experimental plots were fully randomised. Each experimental plot contained five trees. The soil in the orchard was Epicalcari-Endohypogleyic Cambisol: heavy clay loam containing 2.8% of humus, 139 mg/kg P, 158 mg/kg K, 5100 mg/kg Ca, 1168 mg/kg Mg, with pH 7.2 (in 1 mol/L KCl extract). Each spring ammonium nitrate was applied at the rate of 50 kg/ha. Orchard floor management combined frequently mown grass in the alleyways with 1.0 m wide herbicide strips along tree rows. The orchard was not irrigated, and fruitlets were not thinned.

The average temperatures of experimental periods were lower by 1.1–1.5°C in comparison to the perennial average; the amount of rainfall in 2007 was 40% higher than perennial average (Table 1).

The yield was recorded for the whole experimental plot and then recalculated as tons per hectare. Random samples of fifty apples per plot were used to determine individual fruit weight. Laboratory measurements were conducted on random samples of ten fruit. For leaf chemical analysis random samples of 50 leaves taken from middle part of shoots were used. The content of leaf and fruit nitrogen was measured by the Kjeldahl method using Tecator Digestion System DK 20 (VelP Scientifica, Usmate, Italy) and Semi-automatic Distillation Unit UDK139 (VelP Scientifica, Usmate, Italy). The measure of potassium content was determined by the flame photometry with Jenway PFP7 (Bibby Scientific Limited, Staffordshire, UK), and the contents of calcium and magnesium by atomic absorption spectrophotometry (AAnalyst 200, Perkin Elmer precisely, Waltham, USA). Fruit flesh firmness (N) was measured with penetrometer (FT-327, TR Turoni, Forli, Italy) with 11 mm diameter probe; soluble solids content (SSC) (°Brix) – with a digital refractometer (ATAGO 101, Atago Co., Ltd., Tokyo, Japan); starch conversion – with 0.1N iodine and potassium iodine solution, according to the scale 1–10. The maturity index of the fruit was calculated as the ratio of firmness, F, to the product R × S, where R is the soluble solids concentration and S is the starch conversion.

In order to determine storage properties of fruit, random samples of one hundred apples from each experimental plot were stored for 180 days. The weight loss (in percentage) that occurred in fruit during storage was measured by weighing; the flesh firmness and soluble solids content were analysed as described above. Bitter pit and rot incidence (in percentage) were recorded at the end of storage.

The data were analyzed using the analysis of variance (ANOVA) procedure, and means were separated by the Duncan's multiple range tests with $P \leq 0.05$.

RESULTS AND DISCUSSION

During both years of experimentation, the control trees produced higher yields than those treated with fertilizers (Table 2). Therefore, it is unlikely

Table 1. Average air temperature and rainfall in the period of May–October. Records of iMETOS® meteorological station in Babtai

Month	Air temperature (°C)			Rainfall (mm)		
	2007	2008	perennial average	2007	2008	perennial average
May	11.4	9.9	12.3	104.4	41.8	47.7
June	15.3	14.0	15.5	72.2	59.6	63.0
July	15.2	16.0	17.5	173.6	57.0	84.6
August	16.5	15.8	16.4	42.8	88.4	65.7
September	10.5	9.9	12.2	57.8	22.8	44.6
October	5.5	6.5	6.9	57.2	71.4	56.4
Average of the period	12.4	12.0	13.5	508.0	341.0	362.0

Table 2. Yield and fruit weight of cv. Ligol apple cultivar

Treatment	Yield (t/ha)		Average fruit weight (g)	
	2007	2008	2007	2008
Control	57.1	65.0	115	138[a]
Liquid Ca fertilizers × 4	51.6	64.1	121	130[a]
Liquid Ca fertilizers × 8	55.9	62.6	131	151[ab]
Calcium nitrate × 8	54.2	60.2	123	172[b]
	ns	ns	ns	

The means followed by the same letter in column are not significantly different at $P \le 0.05$; ns – non signifi–cant at $P \le 0.05$

that application of foliar fertilizers influenced the yield. In 2007 there is a significant difference in average fruit weights among treatments. However, in 2008, the control trees and trees sprayed four times with liquid calcium fertilizer produced the smallest average fruit weights, 138 and 130 g, respectively. The trees treated with calcium nitrate yielded, on average, significantly larger fruit. The yield and average apple weight affect the incidence of physiological disorders: bitter pit usually damages large apples from less fertile trees (Jackson 2003).

In 2007 the tendency of leaf calcium increase was observed when fertilizers were aplied 8 times (Table 3). Fertilizers had no effect on nitrogen, potassium and magnesium content in the leaves. Some researches use (K + Mg)/Ca ratio for prediction of calcium deficiency related disorders in fruits (Sió et al. 1999). Lower (K + Mg)/Ca ratio is desirable. In our experiment it was similar in all the treatments.

In 2008 calcium fertilizers had no effect on leaf calcium content. Apples treated 8 times with liquid calcium fertilizers had lower Mg content in comparison with the other fertilizer treatments. Differences of the rest nutrient content and (K + Mg)/Ca ratio in the leaves were insignificant (Table 3).

In 2007 fertilizers did not have a significant effect on the mineral nutrient content of the fruit. It was noted in the literature that application of calcium fertilizers may significantly decrease N/Ca and K/Ca ratios in fruit (Domagała-Świątkiewicz and Błaszczyk 2007, Casero et al. 2009). Such changes generally have a positive impact on apple storage quality (Piestrzeniewicz and Tomala 2001). Similar tendencies were observed in our experiment: trees sprayed with calcium fertilizers produced fruit with lower potassium content and lower N/Ca, K/Ca and Mg/Ca ratios (Table 4).

In 2008, N/Ca, K/Ca, and Mg/Ca ratios were even lower than in the previous year (Table 4). Fruits from trees fertilized four times with liquid calcium had significantly lower Mg/Ca ratio than thoset from control trees, or trees sprayed eight times with calcium nitrate.

In 2007, the fruit flesh firmness at harvest of trees sprayed four times was significantly higher in comparison with fruit produced by control trees (Table 5). Similar flesh firmness was present in all treatments where calcium fertilizers were applied. This suggests that more intense application of calcium fertilizers does not increase fruit flesh firmness. In addition, application of calcium fertilizers does not influence soluble solids content nor starch conversion index. Apples produced by control trees were more mature in comparison with those yielded by trees sprayed with calcium fertilizers.

The apple flesh firmness was lower in the second year of the experiment. Again, the fruit from trees sprayed four times had the highest flesh firmness at harvest, but no statistically signifficant differences between control and treated plants, nor among the treatments were established (Table 5). The soluble solids content (SSC) and starch conversion index were similar to those of the year before.

Table 3. Content of mineral nutrients in the leaves of cv. Ligol apple tree

Treatment	Leaf nutrient content (%)				(K + Mg)/Ca
	Ca	N	K	Mg	
2007					
Control	1.38	2.2	0.76	0.27	0.74
Liquid Ca fertilizers × 4	1.33	2.1	0.79	0.23	0.78
Liquid Ca fertilizers × 8	1.64	2.1	0.83	0.27	0.67
Calcium nitrate × 8	1.62	2.3	0.86	0.25	0.71
	ns	ns	ns	ns	ns
2008					
Control	1.29	1.89	1.15	0.30[ab]	1.13
Liquid Ca fertilizers × 4	1.44	1.87	1.13	0.32[b]	1.01
Liquid Ca fertilizers × 8	1.20	1.95	1.07	0.26[a]	1.11
Calcium nitrate × 8	1.22	1.94	1.05	0.31[b]	1.11
	ns	ns	ns		ns

The means followed by the same letter in column are not significantly different at $P \le 0.05$; ns – non signifi–cant at $P \le 0.05$

Table 4. Content of mineral nutrients in cv. Ligol apples

Treatment	Fruit nutrient content (%)				N/Ca	K/Ca	Mg/Ca
	Ca	N	K	Mg			
2007							
Control	0.022	0.31	0.47	0.027[ab]	14.1	21.4	1.2
Liquid Ca fertilizers × 4	0.027	0.28	0.45	0.029[b]	10.4	17.5	1.1
Liquid Ca fertilizers × 8	0.029	0.33	0.39	0.025[a]	11.4	13.5	0.9
Calcium nitrate × 8	0.025	0.31	0.39	0.026[a]	12.4	15.5	1.0
	ns	ns	ns		ns	ns	ns
2008							
Control	0.035	0.25	0.57	0.030	7.1	16.3	0.9[b]
Liquid Ca fertilizers × 4	0.042	0.29	0.61	0.031	6.9	14.6	0.7[a]
Liquid Ca fertilizers × 8	0.040	0.27	0.56	0.031	6.8	14.2	0.8[ab]
Calcium nitrate × 8	0.033	0.25	0.58	0.030	7.6	17.6	0.9[b]
	ns	ns	ns	ns	ns	ns	

Means followed by the same letter in columns are not significantly different at $P \leq 0.05$; ns – non significant at $P \leq 0.05$

Calcium fertilizers did not influence their values. The maturity index was the same in all treatments.

Apples at harvest were not affected by bitter pit in either year of the experiment. At the end of storage, bitter pit incidence reached 1.5–3.0% in apples picked in 2007 (Table 6). The eight-time application of liquid calcium fertilizers significantly reduced bitter pit incidence after storage. Bitter pit did not damage the 2008 yield. Moreover, fruit calcium content was higher, N/Ca, K/Ca, and Mg/Ca ratios were lower than in the fruit picked in 2007. Weather conditions may have affected tree nutrition. In 2007, there was a high amount of precipitation. Both excessive moisture and drought adversely affect plant calcium nutrition (Wójcik 1998).

High calcium concentration and low K/Ca and Mg/Ca ratios are a prerequisite for good fruit storage. According to Wińska-Krysiak and Łata (2010), K/Ca ratio in bitter pit-free apples of Ligol

Table 5. Cv. Ligol apple quality at harvest

Treatment	Flesh firmness (N)	SSC (°Brix)	Starch conversion index (1–10 scale)	Maturity index
2007				
Control	71.2[a]	11.2	8.8	0.07[a]
Liquid Ca fertilizers × 4	74.2[b]	11.6	8.6	0.08[b]
Liquid Ca fertilizers × 8	73.6[ab]	11.3	8.9	0.08[b]
Calcium nitrate × 8	73.3[ab]	11.2	8.8	0.08[b]
		ns	ns	
2008				
Control	62.4	11.5	8.5	0.07
Liquid Ca fertilizers × 4	67.0	11.4	8.5	0.07
Liquid Ca fertilizers × 8	63.4	11.2	8.7	0.07
Calcium nitrate × 8	62.5	11.6	7.9	0.07
	ns	ns	ns	ns

Means followed by the same letter in columns do not differ significantly at $P \leq 0.05$; ns – non significant at $P \leq 0.05$; SSC – soluble solids content

Table 6. Cv. Ligol apple quality after storage

Treatment	Bitter pit incidence (%)	Rot incidence (%)	Natural weight loss (%)	Flesh firmness (N)	Soluble solids content (°Brix)
2007–2008					
Control	3.0^{b}	11.8	5.33^{b}	54.0^{a}	10.4
Liquid Ca fertilizers × 4	2.5^{b}	11.5	4.90^{ab}	65.7^{b}	11.1
Liquid Ca fertilizers × 8	1.5^{a}	11.4	4.62^{a}	66.7^{b}	11.2
Calcium nitrate × 8	1.9^{ab}	11.1	4.73^{ab}	55.9^{a}	10.5
		ns			ns
2008–2009					
Control	0	16.0	5.9	55.0	11.0
Liquid Ca fertilizers × 4	0	10.9	5.8	57.2	10.9
Liquid Ca fertilizers × 8	0	15.4	6.2	53.0	10.4
Calcium nitrate × 8	0	15.6	6.4	56.9	10.5
	ns	ns	ns	ns	ns

Means followed by the same letter in columns do not differ significantly at $P \leq 0.05$; ns – non significant at $P \leq 0.05$

cultivar was 39.1, whereas in apples with bitter pit symptoms, this ratio reached 62.6. In our experiment bitter pit incidence was low and we did not observe such high K/Ca ratios.

The amount of rotten fruit after storage was similar in all treatments from the 2007 harvest (Table 6). In 2008, the apples were somewhat more affected by rot. Calcium fertilizers did not decrease rot incidence in our experiment. However, some research demonstrates that calcium salts may have a suppressive effect against the rot pathogens and could be used as part of a disease management program (Biggs 1999). Calcium chloride is effective for fungi induced rot depression (Conway et al. 2002), whereas we used calcium nitrate.

Calcium fertilizers tended to decrease the natural fruit weight loss of stored apples picked in 2007 (Table 6). The weight loss of the fruit from trees sprayed eight times with liquid calcium fertilizer was significantly lower in comparison with the control. In 2008, fertilizers did not have an effect on fruit weight loss. A similar situation occurred with fruit flesh firmness. Apples sprayed with liquid calcium fertilizers were firmer in comparison with the control after the 2007 storage experiment. In 2008, fruit firmness after storage was similar in all treatments. Apples picked in 2007 lost 9–24% of flesh firmness compared to 9–16.6% a year later. Fertilizers did not affect fruit SSC in either year of the experiment; however, the SSC slightly decreased after storage.

The effect of calcium fertilizers on apple quality and storage parameters was moderate in our experiment. Quite low N/Ca, K/Ca, and Mg/Ca ratios in fruit prevented calcium defficiency related disorders. As mentioned earlier, higher levels of calcium, and lower ratios of N/Ca, K/Ca, and Mg/Ca usually resulted in lower incidence of bitter pit. The soil in our experiment was very rich in calcium, but high soil calcium content did not prevent calcium deficiency related disorders in some years. In earlier experiments, we recorded bitter pit incidence up to 35.7% on cv. Sinap Orlovskij and up to 6% in cv. Shampion apples. Such disorders were observed after a very warm season with low amounts of rainfall, which increased the K/Ca ratio in fruit. Calcium fertilizers reduced bitter pit incidence after extreme growth seasons. In the next two years bitter pit incidence was low and calcium fertilizers did not have a significant effect (Lanauskas and Kviklienė 2005, 2006).

In spite of the high calcium content in soils, and the high potential of its uptake by apple trees, calcium deficiency remains a common factor for many disorders in apple fruits (Wójcik 1997). Favourable weather conditions may positively influence the fruit supply with calcium in normal years. Noting the importance of weather conditions for apple tree nutrition Švagždys and Viškelis (1999) distinguish ‘potassium years’ and ‘calcium years.’ In our experiment, the high yields and relatively small fruit also reduced the risk of disorders.

No statistically signifficant correlations between nutrient content in leaves, fruit, or fruit quality parameters were established. Although positive effects of calcium fertilizers on apples is widely reported; regular relationships between nutrient content and physiological fruit disorders are often absent (Gallerani et al. 1990, Gastol and Poniedzialek 2005).

The translocation of calcium within the plant and the causes of calcium deficiency in fruit are still a matter of conjecture. Gibberellins have been shown to inhibit calcium translocation. Varying levels of gibberellic acid due to environmental factors could be the cause of the observed differences in the calcium content in fruit between different years and different regions (Saure 2005).

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Received on June 7, 2012

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