Effects of Calcium Content and Calcium Applications on Softening of 'Hayward' Kiwifruit

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Abstract

Despite the importance of calcium content and the effects of calcium applications in many fruit species, no clear relationship between fruit Ca content and early softening is established in kiwifruit. Diverse results have been reported with Ca applications in kiwifruit, particularly regarding fruit firmness. Thus, experiments were undertaken to define the influence of fruit Ca status and Ca applications on kiwifruit quality, with an emphasis on fruit softening in cold storage. Fruit samples from the major kiwifruit cultivation areas in Chile were analysed for Ca content in two seasons, and related to the time required for the fruit to soften to 18N when maintained at 0°C and 90% RH. Although the time to reach 18N varied widely, no significant relationship was established, suggesting that additional factors to Ca content are relevant in determining softening susceptibility. During two seasons Ca was applied to fruit by spraying vines (fruit), and by postharvest dipping. In 2003/2004, $CaCl_2$ was applied by spraying in 2 orchards at 0.8% commercial product (1700 ppm Ca), during fruit development (9 and 17 applications), or by one postharvest dip treatment with 2% of $CaCl_2$ (4250 ppm Ca). In vines sprayed 17 times, fruit Ca content was higher, and storage life 50–80% greater, than fruit from vines sprayed 9 times and in fruit from control vines. In 2004/2005, 600 ppm Ca was applied 4 times preharvest using 3 commercially-available sources (plus, one water-applied control). In a different experiment, the same sources of Ca at 2000 ppm were applied as postharvest dips. Preharvest Ca application produced phytotoxic effects on both leaves and fruit; postharvest applications did not produce any phytotoxicity but in both cases significantly increased storage life. Reducing the concentration and times of Ca applications (up to 4) in 2004/2005 eliminated phytotoxic effects, but the beneficial effects on fruit quality were reduced.

INTRODUCTION

One of the main reasons for kiwifruit storage is to maintain fruit firmness and avoid excessive softening that limits postharvest life. For many fruit species, premature softening is linked to fruit calcium content, attained either naturally or following pre- or postharvest Ca applications. However, unlike other fruit species, such as apple, where there is agreement on the positive effect of Ca (Faust and Shear, 1968; Conway, 1987), in kiwifruit contradictory results have been obtained. Thus, no clear relationship between Ca content and early softening exists in kiwifruit (Tagliavini et al., 1995). Further, diverse results were reported following calcium applications in kiwifruit, mainly on fruit firmness (Xie et al., 2003; Antunes et al., 2005; Gerasopoulos and Drogoudi, 2005). The objective of this work was to determine the relationship between Ca content of specific fruit lots and their susceptibility to postharvest softening, and the effect of pre- and postharvest Ca applications on kiwifruit quality and storage life, with particular emphasis on softening.

MATERIAL AND METHODS

Fruit Ca Levels and Softening

This survey was carried out on 23 orchards in the season 2003/2004 and in

36 orchards in 2004/2005 to determine if there was a relationship between fruit Ca content at harvest with softening during storage. Five uniform mature plants per orchard were selected and fruit were harvested at 6.2–6.5% soluble solids content (SSC), and size of 90–110 g fruit weight. Ca content was determined in a sample of 5 fruit per plant by atomic absorption spectrophotometry. Fruit was cured for 48 hours at ambient temperature and then stored at 0°C and 90% RH. At fortnightly intervals a sample of 7 fruit per orchard was used to measure fruit firmness, this was performed up until the fruit softened to 18 N. Days at 0°C to reach 18 N (T-18N) and softening index (daily loss of firmness during storage; SI) were calculated. According to their fruit Ca levels, orchards were classified into three groups: high ($\geq$0.20% Ca dry matter), middle (0.17–0.19% Ca) and low level ($\leq$0.16% Ca), and the average T-18N and SI per group were determined. The data were subjected to correlation and regression analysis to determine the relationship between fruit Ca content and storage duration measured as days to reach 18 N (T-18N) and softening index (SI).

Ca Applications and Softening

This study was conducted over a period of two growing seasons, 2003/2004 and 2004/2005. In the first season, 4 treatments were applied in two orchards: non-sprayed control; $CaCl_2$ at 0.8% (1700 ppm Ca) sprayed 17 times weekly from one month after full bloom (FB); $CaCl_2$ at 0.8% sprayed 9 times fortnightly; and one postharvest dipping of $CaCl_2$ at 2% (4250 ppm Ca). Experimental lay-out was a complete randomised design with 4 treatments and 4 replications of 1 plant each. In the second season, two separate experiments were carried out, both in two orchards. The preharvest experiments consisted of 3 different Ca sources sprayed 4 times at 600 ppm Ca each (fortnightly from 2 months after FB), one water spray treatment and one non-sprayed control. To assess the effects of postharvest Ca treatments, the 3 different Ca sources were used separately as dipping solutions of 2000 ppm. Fruit was harvested, stored and sampled as indicated above. All experiments were established as complete randomised designs with 3 replicates of 1 plant each for preharvest and postharvest applications.

RESULTS AND DISCUSSION

Ca Levels

In the first season (2003/2004), no differences existed in the time required for fruit with different Ca levels to soften to 18N at 0°C (Tables 1, 2 and 3), since fruit with higher Ca content lasted 54 days before reaching 18 N, while those with the lower Ca content took 56 days to reach 18N. Data were variable in all treatments. There was no significant correlation ($R = -0.146$) between fruit Ca content and duration time to reach 18N at 0°C in cold storage (Table 4 and Fig. 1). In the second season similar results were obtained (data not shown), strongly suggesting that Ca content by itself does not seem to be the dominant factor in the susceptibility of kiwifruit to softening at 0°C.

Ca Applications

In the first season $CaCl_2$ applications had, in general, a favourable effect on fruit (Table 5) with Ca content increasing when vines were sprayed 17 times. In contrast with results from Antunes et al. (2005), there was no effect of Ca application on other characteristics at harvest including firmness, dry matter and soluble solids. Generally, Ca treatments reduced fruit softening, particularly in Orchard 1 (Table 5), and increased time taken to reach T-18N, particularly when 17 applications were given. Phytotoxicity to leaves and fruit was a major problem with the preharvest treatments that became apparent 15 days after the beginning of the sprays. Postharvest treatments had a beneficial effect in reducing softening and increasing time to reach 18 N in fruit from both orchards, even though no significant increase occurred in Ca content.

In the second season, when both number and concentration of preharvest Ca applications were reduced, no phytotoxicity was induced in leaves or in fruit, but the beneficial effects on fruit Ca content and on softening were also reduced (Table 6). This agrees with Gerasopoulos et al. (1996), who emphasised the importance of high concentrations and sufficient applications in achieving positive Ca effects. There were no differences obtained from the different Ca sources. Postharvest treatments had virtually no effect on measured attributes in this season (Table 7), probably because of the reduced Ca concentration used in dipping solution; these results differ from those of Antunes et al. (2005), who found that immersion in 1% $CaCl_2$ improved storage potential.

CONCLUSIONS

No clear relationship was established between natural fruit Ca content from different orchards and their susceptibility to postharvest softening at 0°C.

The pre- and postharvest applications of Ca to fruit sometimes increased fruit Ca content and delayed postharvest softening at 0°C, but this was dependent on the concentration and frequency of Ca applied.

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Tables

Table 1. Fruit softening in orchards with high fruit calcium level ($\geq$ 0.20% of dry matter). Season 2003/2004.

Orchards	Regions	Fruit Ca (% DM) [1/]	SI [2/] ($N\ day^{-1}$)	T-18N [3/] (days)
Quinta de Tilcoco	VI	0.20	0.780	69
San Fernando	VI	0.20	0.944	58
Teno	VII	0.27	1.403	42
Tutuquén	VII	0.25	1.123	62
Romeral	VII	0.24	1.198	46
Sarmiento	VII	0.23	1.546	34
Curicó	VII	0.23	1.203	54
Parral	VII	0.20	0.802	78
Los Angeles	VIII	0.23	1.007	48
Pillanlelbún Alto	IX	0.20	1.149	53
Mean		0.23	1.016	54

[1/] % DM= Dry matter; [2/] SI= softening index; [3/] T-18N= time in days to reach 18 N.

Table 2. Fruit softening in orchards with medium fruit calcium level (0.17% – 0.19% of dry matter). Season 2003/2004.

Orchard	Regions	Fruit Ca (% DM) [1/]	SI [2/] ($N\ day^{-1}$)	T-18N [3/] (days)
Limache	V	0.18	0.802	71
Huelquén	RM	0.19	0.820	68
Cardonal	RM	0.19	0.606	77
Naicura	VI	0.19	0.619	96
Lolol	VI	0.17	0.789	50
Talca	VII	0.19	1.768	30
Los Niches	VII	0.17	1.737	32
Angol	IX	0.19	0.989	59
Futrono	X	0.17	1.002	76
Mean		0.18	1.042	62.1

[1/] % DM= Dry matter; [2/] SI= softening index; [3/] T-18N= time in days to reach 18 N.

Table 3. Fruit softening in orchards with low fruit calcium level ($\leq$ 0.16% of dry matter). Season 2003/2004.

Orchards	Regions	Fruit Ca (% DM) [1/]	SI [2/] ($N\ day^{-1}$)	T-18N [3/] (days)
La Serena	IV	0.12	1.461	39
Limache	V	0.16	0.935	70
Huelquén	RM	0.14	0.682	66
Temuco	IX	0.16	1.149	51
Mean		0.15	1.056	56.5

[1/] % DM= Dry matter; [2/] SI= softening index; [3/] T-18N= time in days to reach 18 N.

Table 4. Correlations between fruit calcium content and time to reach 18N at 0°C. Season 2003/2004.

Variable	Fruit Ca % DM[1/]	
	R	Probability
T-18N [2/]	-0.146	0.508
SI (N/day)[3/]	0.185	0.410

[1/] % DM= Dry matter; [2/] SI= softening index; [3/] T-18N= time in days to reach 18 N.

Table 5. Calcium applications in pre and postharvest on fruit softening. First season (2003/4).

Treatments	Harvest				Postharvest		
	Fruit Ca (% DM)[1/]	Firm. (N)	ISSC [2/] (ºBrix)	% DM	FSSC [3/] (°Brix)	SI [4/] (N/day)	T-18N [5/] (days)
Orchard 1: Cardonal, Huelquén. RM.							
Control	0.20 b [6/]	73.5 a	5.9 a	17.4 b	13.4 b	0.89 d	60 c
0.8% $CaCl_2$, 17sprays	0.43 a	76.1 a	6.4 a	18.4 ab	14.0 b	0.53 a	108 a
0.8% $CaCl_2$, 9 sprays	0.17 b	74.3 a	6.4 a	19.2 a	14.3 b	0.62 b	95 b
Postharvest	0.22 b	73.5 a	5.9 a	17.4 b	13.7 b	0.76 c	74 b
Orchard 2: Quinta de Tilcoco. VI Region.							
Control	0.15 c	62.4 a	6.8 a	16.4 b	13.2 b	0.89bc	50 b
0.8% $CaCl_2$, 17sprays	0.20 a	68.9 a	6.9 a	16.6 b	14.4 a	0.71ab	65 a
0.8% $CaCl_2$, 9 sprays	0.18 b	69.0 a	6.9 a	17.4 b	13.3 b	0.94 c	53 b
Postharvest	0.19 ab	62.4 a	6.7 a	16.4 b	13.5 ab	0.67 a	69 a

[1/] % DM= Dry matter; [2/] ISSC = Initial soluble solids content; [3/] FSSC: final soluble solids content; [4/] SI= softening index; [5/] T-18N= time in days to reach 18 N; [6/] Values within columns followed by the same letter are not significantly different at 0.05%.

Table 6. Calcium applications at pretharvest on kiwifruit softening. Second season (2004/2005).

Treatments	Harvest				Postharvest		
	Fruit Ca (% DM)[1/]	Firm. (N)	ISSC [2/] (ºBrix)	% DM	FSSC [3/] (°Brix)	SI [4/] (N/day)	T-18N [5/] (days)
Orchard 1: San Fernando. VI Region.							
Control	0.17 b [7/]	93.9 a	6.1 a	16.9 a	12.7 a	0.94 a	82 a
Water	0.19 ab	91.8 a	5.9 a	17.2 a	12.7 a	0.85 a	85 a
Antibitt [6/]	0.17 b	89.6 a	6.6 b	18.4 a	14.3 a	0.80 a	87 a
Wuxal [6/]	0.25 a	94.1 a	6.2 a	17.3 a	13.3 a	0.89 a	85 a
Basfoliar [6/]	0.24 ab	92.9 a	6.0 a	17.1 a	12.6 a	0.85 a	87 a
Orchard 2: Teno. VII Region.							
Control	0.22 a	74.5 a	7.2 a	15.1 a	13.0 a	0.54 b	100 a
Water	0.23 a	74.1 a	7.7 a	15.8 a	13.6 a	0.54 b	103 a
Antibitt	0.22 a	71.0 a	7.4 a	15.8 a	13.1 a	0.45 ab	115 a
Wuxal	0.24 a	69.8 a	7.3 a	15.1 a	13.4 a	0.49 ab	111 a
Basfoliar	0.23 a	69.8 a	7.8 a	15.7 a	13.9 a	0.49 ab	106 a

[1/] % DM= Dry matter; [2/] ISSC = Initial soluble solids content; [3/] FSSC: final soluble solids content; [4/] SI= softening index; [5/] T-18N= time in days to reach 18 N; [6/] 4 sprays at 600ppm Ca. [7/] Values within columns followed by the same letter are not significantly different at 0.05%.

Table 7. Postharvest calcium applications effect on quality attributes and softening at 0°C. Second season (2004/2005).

Treatments	Harvest				Postharvest		
	Fruit Ca (% DM)[1/]	Firm. (N)	ISSC [2/] (ºBrix)	% DM	FSSC [3/] (°Brix)	SI [4/] (N/day)	T-18N [5/] (days)
Orchard 1: San Fernando. VI Region.							
Control	0.18 a [7/]	89.3 a	6.5 a	16.9 a	12.7 a	0.94 a	82 a
Antibitt [6/]	0.16 a	88.9 a	6.1 a	16.6 a	13.4 a	0.76 a	91 a
Wuxal [6/]	0.15 a	88.9 a	6.1 a	17.8 a	13.5 a	0.80 a	89 a
Basfoliar [6/]	0.20 a	94.0 a	6.1 a	16.9 a	12.9 a	0.80 a	96 a
Orchard 2: Teno. VII Region.							
Control	0.22 a	73.0 a	6.8 a	15.1 a	13.0 a	0.54 a	100 a
Antibitt	0.21 a	74.7 a	6.8 a	15.1 a	12.7 a	0.49 a	121 b
Wuxal	0.20 a	70.3 a	7.0 a	14.7 a	13.2 a	0.54 a	102 a
Basfoliar	0.23 a	69.1 a	7.2 a	15.1 a	12.9 a	0.49 a	105 a

[1/] % DM= Dry matter; [2/] ISSC = Initial soluble solids content; [3/] FSSC: final soluble solids content; [4/] SI= softening index; [5/] T-18N= time in days to reach 18 N; [6/] dipping at 2000 ppm Ca [7/] Significant differences at 0.05%.

Figures

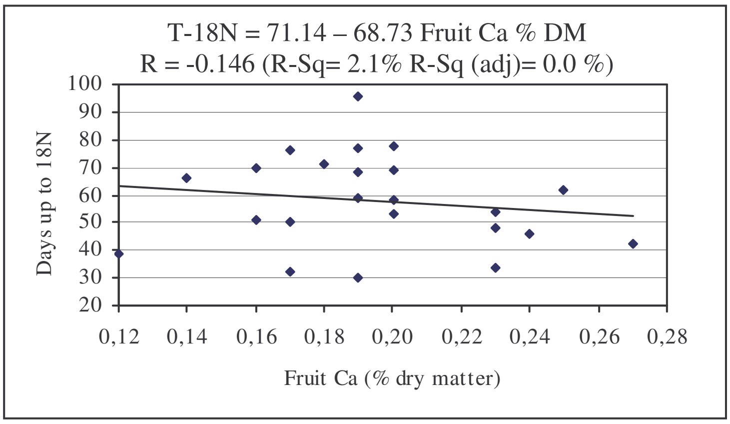

Fig. 1. Relationship between fruit Ca content (% d.m) and time (days) to reach firmness of 18N. Season 2003/2004.