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Summer-pruning and preharvest calcium chloride sprays affect storability and low temperature breakdown incidence in kiwifruit

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Abstract

Shoots with an intermediate size of kiwifruit, cv. Hayward, were terminated to five leaves and long shoots were topped or left unpruned at 2 days after petal drop. Fruit on the vines were either untreated or given an additional treatment of 1% calcium chloride ($CaCl_2$), four times during fruit development. Flesh firmness, soluble solids content (SSC) and calcium (Ca) content in the fruit pericarp, were measured in fruit harvested from small, medium and long shoots. Fruit were stored at 0 °C for up to 42 weeks. Low temperature breakdown (LTB) incidence was assessed after 5 days of ripening at 20 °C.

Summer-pruning increased fruit SSC and Ca content by 0.5 and 30%, respectively, while $CaCl_2$ sprays increased the fruit Ca content and firmness by 64 and 13 N, respectively. Fruit harvested from small, medium or long shoots had similar SSC and firmness at harvest and during storage, and Ca content at harvest. During storage, fruit receiving $CaCl_2$ sprays, or both $CaCl_2$ sprays and summer-pruning, softened more slowly, increasing storage life potential by 10–12 weeks, compared with untreated fruit. Summer-pruning did not affect fruit potential storability. Lower LTB incidence occurred in fruit from summer-pruning, preharvest $CaCl_2$ spray treatments, or when both treatments were applied. Less LTB occurred in fruit from short shoots compared with those harvested from medium and long shoots.
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1. Introduction

Summer-pruning increases kiwifruit (*Actinidia deliciosa* [A. Chev.] C.F. Liang et A.R. Ferguson) weight and yield (Galliano et al., 1990; Chouliaras et al., 1995; Miller et al., 2001; Thorp et al., 2003), and is used commonly by growers. The benefits may occur because of direct effects of summer-pruning on the source–sink and hormonal balance, as well as indirect effects on inducing better light penetration and air circulation inside the canopy. However, effects of summer-pruning on other aspects of kiwifruit quality are variable, and

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evidence shows that responses may be confounded by the fruit position on the vine (Miller et al., 2001), or the shoot diameter (Thorp et al., 2003). Effects of summer-pruning on the storage ability in kiwifruit or other fruit crops are less documented.

Considerable attention has be given to calcium (Ca) application to kiwifruit (Hopkirk et al., 1990; Gerasopoulos et al., 1996; Basiouny and Basiouny, 2000) since it was found to extend storability and potentially be related with the appearance of pitting incidence (Thorp et al., 2003). Greater Ca contents in fruit may maintain membrane permeability and slow ripening processes during storage (Ferguson, 1984; Conway, 1987).

Low temperature breakdown (LTB) is a disorder inducing kiwifruit quality losses during and after cold storage. Symptoms of LTB include appearance of grainy tissue in the outer pericarp and development of diffuse pitting in association with development of a water-soaking appearance (Lallu, 1997). Bauchot et al. (1999) found that the "grainy" tissue of the LTB-affected fruit was due to the presence of air bubbles trapped within some of the cells, while the presence of higher than normal amounts of cell wall material and levels of galactosyl residues in the cell wall fraction suggested that cell wall metabolism was disrupted. Storage temperature (Lallu, 1997) and elevated CO_2 in controlled atmosphere storage conditions (Arpaia et al., 1985) may influence the development of the LTB symptoms. The extent to which cultural practices such as summer-pruning and Ca sprays may affect susceptibility of fruit to LTB incidence is not known.

The objective of the present study was to investigate the effects of summer-pruning and preharvest $CaCl_2$ sprays on the fruit quality and storability of 'Hayward' kiwifruit, especially in relation to LTB incidence. At harvest, fruit were separately harvested from short, medium and long sized shoots to investigate any possible fruit quality related effects and therefore reduce variability associated with treatment effects.

2. Materials and methods

2.1. Plant material and handling

The experiment was conducted in a commercial kiwifruit (*Actinidia deliciosa* [A. Chev.] C.F. Liang et A.R. Ferguson, cv. Hayward) orchard located in Pieria, central Macedonia, Greece. The vines were 10 years old, planted in a North–South orientation, trained in a T-bar shape and had received modified long-winter pruning. Fertilisation and irrigation were conducted at recommended rates to ensure optimum yield and quality.

Forty vines were selected for crop vegetative and crop load uniformity at random within the orchard. The treatments applied were pruning, which included summer pruned and non-summer pruned vines, and preharvest $CaCl_2$ sprays, which included spraying with water or 1% $CaCl_2$. Each treatment level was applied in 10 randomly chosen replicate vines.

In pruned vines, 2 days after petal drop, shoots of an intermediate size (approximately 50 cm and 8–10 leaves) were snapped on the fifth leaf after the last fruit and long fruiting shoots (>100 cm and >20 leaves) were only topped to 20 leaves. Preharvest $CaCl_2$ spray applications consisted of hand-spraying the fruit to run off with 1% $CaCl_2$ (96% dehydrated, Sigma–Aldrich, St. Louis, MO, USA) with Tween 20 as a surfactant, at 15 day intervals (93, 108, 123 and 138 days after petal fall).

2.2. Fruit quality and storage behaviour

Twenty-four weeks after petal fall and when SSC reached an average of 6.2%, fruit were separately harvested from short, medium and long shoots and each pruning and preharvest $CaCl_2$ treatment vines, transferred immediately to the laboratory and selected for uniform shape, size and weight.

Upon harvest, fruit firmness, SSC and Ca contents were measured in a total of 25 fruit replicates from each shoot type (short, medium and long), pruning and $CaCl_2$ treatments. Firmness was measured on both sides of the fruit after removal of the peel, using a Chatillon penetrometer, fitted with a 7.9 mm tip (AMETEK, Largo, USA), and SSC was measured using a digital refractometer (model PR-1, Atago, Japan) on juice from fruit slices. For the determination of Ca, fruit discs were separated from skin and seeds. Ten grams of a 1:1 fruit pericarp–water homogenate was transferred to a serum-capped test tube in which 10 ml of concentrated HCl were added and the tubes were capped and boiled for 20 min. The digested samples were cooled and filtered through Whatman 41 low ash paper. Samples

were spiked with 5 mg L^{-1} strontium chloride during fruit homogenization. The filtrate was diluted to 25 mL with distilled water and Ca determined by Inductively Coupled Plasma (ICP) (model 3300-Axial Transmission, Perkin-Elmer, Wellesley-MA, USA).

Fruit quality during storage was followed for fruit from short, medium and long size shoots and each pruning and $CaCl_2$ treatments. Fruit were cleaned, dipped in a Benomyl solution (600 mg L^{-1}) for 10 s, dried in air and stored for 42 weeks at 0 °C and 95% relative humidity. Flesh firmness and SSC of 12 fruit replicates were determined at 6 week intervals. Following storage, 60 fruit (four replications of 15 fruit from each shoot, pruning, calcium or combined treatments) ripened for 5 days at 20 °C, were cut into two halves and the severity of LTB injury was assessed in light, medium and severe categories.

2.3. Statistical analysis

The experimental design was a completely randomised one, using 10 replicate vines for each shoot type, pruning and $CaCl_2$ level. Statistical analyses were performed using a multi-factor ANOVA, based upon the replicate fruit, using the Statsoft statistical package SPSS (version 9.0, Chicago, USA). Percentage data were arcsine transformed, prior to analyses. LSDs for the comparisons between treatments during storage were also calculated. Treatment means were separated using Duncan comparisons at a *P*-value of 0.05.

3. Results

Shoot size did not significantly affect the fruit pericarp Ca content, firmness or SSC, which averaged 119.2 mg/100 g^{-1} FW, 102.9 N and 6.1%, respectively (Table 1). Fruit Ca contents were 30% higher in fruit from pruned than unpruned vines, but the total pruning treatment effect was only marginally significant ($P = 0.081$). Fruit from pruned vines also had greater SSC (0.5%) but similar flesh firmness, compared with fruit from unpruned vines. $CaCl_2$ sprays increased the fruit pericarp Ca content by 64%, and flesh firmness by 13%, whereas SSC was not affected. No significant interactions were found among treatments (pruning, Ca application and shoot size, data not shown).

Table 1
Mean values of fruit pericarp Ca content, flesh firmness and soluble solids content (SSC) averaged across short, medium and long shoots in kiwifruit, cv. Hayward receiving summer-pruning, preharvest 1% $CaCl_2$ sprays, summer-pruning and $CaCl_2$ sprays, or left unpruned and sprayed with water (control vines)

	Ca (mg/100 g^{-1} FW)	Firmness (N)	SSC (%)
Control	119.2	102.9	6.1
Pruning	155.0	105.1	6.6
$CaCl_2$	195.4	115.9	6.1
Pruning + $CaCl_2$	252.8	110.9	6.2
P-values			
Pruning	0.081	0.731	0.051
$CaCl_2$	< 0.001	0.027	0.244

Probability values less than 0.05 are considered significant. *P*-values for the effects of pruning and $CaCl_2$ applications are shown.

In fruit harvested from short, medium and long sized shoots, changes in flesh firmness and SSC followed similar patterns during storage, and since fruit from medium sized shoots were the bulk of harvested fruit (about 60%) only these responses are presented (Fig. 1A and B).

Untreated fruit lost 80 N of firmness during the first 12 weeks and became fully ripe at week 18 of storage at 0 °C (Fig. 1A). Fruit receiving $CaCl_2$ sprays or both $CaCl_2$ sprays and summer-pruning were firmer than other treatments, thereby increasing storage life by 10–12 weeks, compared with the control or pruning only treatment. Softening of fruit from pruned vines was similar to that of control fruit.

The SSC of control fruit increased to 13.5% by week 12, but further changes were slower to reach 14% by week 42 (Fig. 1B). SSC increases in fruit from untreated vines, pruned vines, and those receiving, or not, $CaCl_2$ sprays, were similar during storage. Ca sprayed fruit had lower SSC than untreated fruit, reaching 12.5 and 13.5% by weeks 12 and 42, respectively.

3.1. LTB incidence and severity

Pruning and $CaCl_2$ treatments increased the percentage of fruit without LTB symptoms (Fig. 2) ($P < 0.001$ and $P = 0.002$, respectively) and decreased the percentage of fruit showing severe symptoms ($P = 0.003$ and 0.049, respectively) (Fig. 3). Irrespective of pruning and calcium spraying treatments, the percentage of fruit without LTB symptoms was greater ($P = 0.047$) in fruit

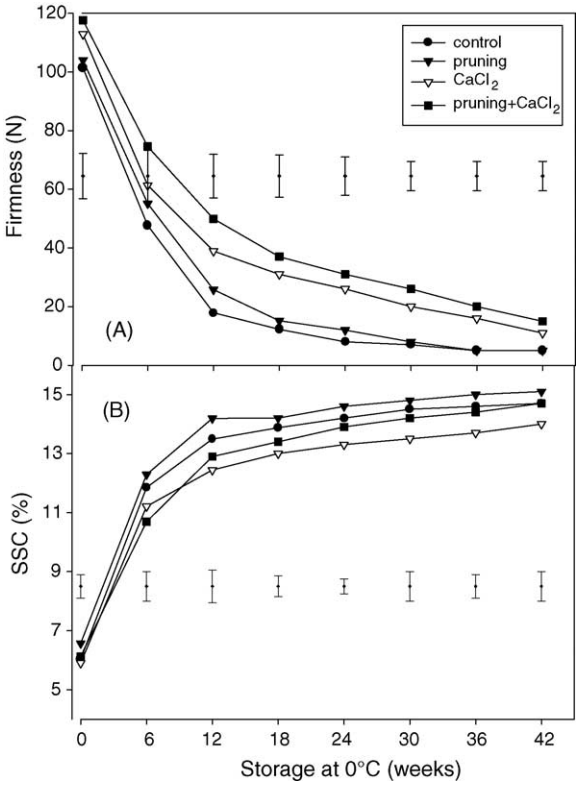

Fig. 1. Firmness (A) and SSC (B) during storage at 0 °C for 42 weeks of kiwifruit obtained from medium sized shoots of vines sprayed with water or 1% $CaCl_2$ preharvest, left unpruned or pruned to 5 leaves 2 days after petal fall or received a combination of spray and pruning. Vertical bars at each sampling point represent the LSD at 95% level of significance.

obtained from short, compared with those harvested from medium or long shoots (Fig. 2). There were no significant treatment effects on the percentage of fruit showing light or medium LTB symptoms, or interactions among treatments in all measured LTB intensities (Fig. 3).

4. Discussion

Summer-pruning applied at 2 days after petal drop increased the fruit yield in kiwifruit by 18% (Chouliaras et al., 1995). In the present study, summer-pruning, applied at the same growth stage as above, proved to be a successful practice to produce kiwifruit of better quality and prolong storability. These effects

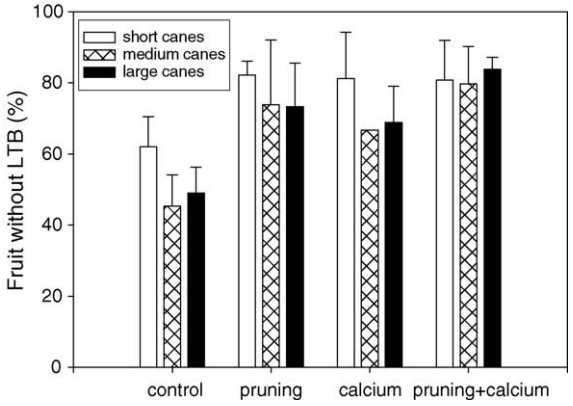

Fig. 2. Percentage (%) of fruit without low temperature breakdown (LTB) symptoms (healthy), obtained from short, medium or long sized shoots of kiwifruit vines left unpruned and sprayed with water (control), pruned to 5 leaves 2 days after petal fall, sprayed with 1% $CaCl_2$ preharvest, or receiving pruning and $CaCl_2$ sprays. Harvested fruit was stored at 0 °C for 42 weeks, then at 20 °C for 5 days when the LTB assessment was made. Vertical bars represent the S.E. of the means.

were also shown to a similar extent when both pruning and pre-harvest $CaCl_2$ sprays were applied.

Summer-pruning increased the pericarp Ca content by 30% and the SSC by 0.5%, both potential attributes of enhanced fruit quality (Table 1). Mierowska et al. (2002) found that pruning increased the photosynthetic rate and the amount of photoassimilates produced in the leaf and fruit tissue, and Tombesi et al. (1993) found that kiwifruit from light exposed positions in the canopy were of better quality and could be stored for longer times. Exposure to the light from the shade was also shown to double the leaf and fruit Ca content in kiwifruit (Xiloyannis et al., 2003). Enhanced fruit quality in pruned vines may also result from changes in the source–sink balance, particularly since the distribution of ^{13}C-photosynthates into the fruit are adversely affected by shoot elongation (Amano et al., 1998).

Preharvest $CaCl_2$ sprays (1% concentration, applied four times during fruit development) extended the kiwifruit storability by 10–12 weeks (Fig. 1). Gerasopoulos et al. (1996) also showed that 0.75 and 1.5% $CaCl_2$ spray applications extended the storage duration by 10 and 18 weeks, respectively. Calcium content of control fruit pericarp was 119.2 mg/100 g^{-1} FW, a high value compared with other reports (Samadi-Maybodi and Shariat, 2003). Calcium chloride sprays

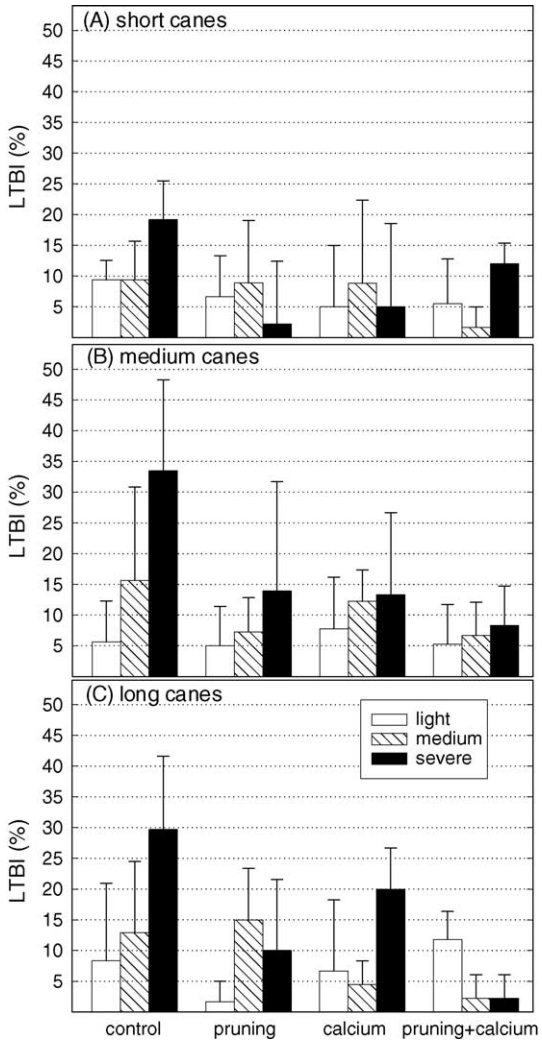

Fig. 3. Percentage (%) of fruit showing light, medium and severe LTB symptoms, in short (A), medium (B) and long (C) sized shoots of kiwifruit vines left unpruned and sprayed with water (control), pruned to 5 leaves 2 days after petal fall, sprayed with 1% $CaCl_2$ preharvest, or receiving pruning and $CaCl_2$ sprays. Harvested fruit was stored at 0 °C for 42 weeks, then at 20 °C for 5 days when the LTB assessment was made. Vertical bars represent the S.E. of the means. LSD at 95% level of significance for light, medium and severe LTB intensities are 16.0, 15.8 and 16.7, respectively.

increased the fruit pericarp Ca content by 64% which may affect storability via its role in binding the pectin in cell walls and subsequent blocking of the access of degradative enzymes (Dematry et al., 1984). However, a 30% increase of fruit Ca content observed in kiwifruit harvested from summer pruned vines was not associated with longer storability. Thus, other factors than Ca alone may be involved in storage extension.

Low temperature breakdown was assessed after fruit were kept for 42 weeks at 0 °C plus 5 days at room temperature (Lallu, 1997). Substantially less LTB incidence was recorded with summer-pruning or preharvest $CaCl_2$ sprays, and to a greater extent with both treatments (Fig. 2). Considering the role of Ca in stabilizing the membranes and that LTB is associated with a disruption of the cell wall metabolism (Bauchot et al., 1999), it is possible that the more pronounced increase in the fruit Ca content, particularly when both summer-pruning and Ca sprays were applied, is related to the reduction in the LTB symptoms.

Development of LTB symptoms in fruit were also affected by shoot size, with 13% more fruit without symptoms when harvested from short size shoots compared with those from medium and long shoots (Fig. 3). No differences in the SSC and Ca contents were found among fruit from different size shoots (Table 1). Amano et al. (1998) found similar ^{13}C-assimilate concentrations among the nodal positions in short sized shoots (self-pinched shoots) whereas a steep gradient existed from the base to the apex of the growing shoots (long size shoots), suggesting that changes in the assimilate distribution among nodal positions may take place for at least some time of shoot growth, and potentially affect the development of LTB symptoms in the harvested fruit during storage.

Recently, the surplus of kiwifruit production makes it essential to find means to maintain fruit quality. Preharvest $CaCl_2$ sprays seem to provide a means not only to extend the storage and market life of this commodity but also to considerably contribute to quality maintenance due to its effects on reducing the occurrence of LTB. Further research is required to determine other preharvest and postharvest factors that affect the LTB incidence and also investigate any possible synergistic effects. Summer-pruning can also have a strong positive effect on kiwifruit quality, which at least in part is associated with increased fruit Ca levels.

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