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Growth Control of 'Glen Ample' and 'Tulameen' Raspberry Cultivars with Single and Repeated ProCa Applications

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Summary

Prohexadione-calcium (ProCa) is used to control vegetative growth in some fruit crops. We evaluated the effects of single and repeated ProCa treatments (100 or 200 ppm) on vegetative growth and cropping potential of biennial-fruiting raspberry (*Rubus idaeus* L.) cultivars 'Glen Ample' and 'Tulameen'. After the initial reduction in primocane growth rate, growth resumed three to four weeks after the first ProCa application. The second application was necessary to achieve permanent reduction in cane height. In 'Glen Ample', primocane growth was reduced by 25 to 28 cm and dry weight by 18 to 26 % following two ProCa treatments. In 'Tulameen' the reduction in primocane growth was 15 cm, and in cane dry weight 19 %, when treated twice with 200 ppm ProCa. After ProCa applications, treated plants produced shorter internodes than the control plants. However, after growth resumption new internodes in the treated plants were longer than in the control plants. Effects on the reproductive performance were evaluated after dormancy release. In 'Glen Ample', repeated ProCa applications reduced the number of lateral shoots, as well as the number and proportion of flower buds, and slightly delayed flowering. Presumably, altered gibberellic acid metabolism had interfered with flower induction. However, the total number of flowers per cane was not affected in either of the cultivars. As ProCa was effective in reducing vegetative growth of primocanes without affecting cropping potential, it may become useful in growth control of biennial fruiting raspberry cultivars. However, timing and number of ProCa applications are extremely crucial.

Key words. crop potential flowering – internode length – prohexadione-calcium – *Rubus idaeus*

Introduction

Red raspberry (*Rubus idaeus* L.) plants grow vigorously, especially, when cultivated in plastic tunnels or greenhouses. However, raspberry yield in relation to vegetative growth is low in comparison with many other cultivated fruit species. More compact plants would facilitate trellising and reduce the need for pruning. Furthermore, ideal plants used in long cane production are compact still with high cropping potential. Therefore, controlling raspberry vegetative growth while maintaining cropping potential would be appealing.

Prohexadione-calcium (ProCa) reduces the vegetative growth in plants through its action on gibberellin biosynthesis (Evans et al. 1999). ProCa is nowadays commonly used in the growth control of apple trees (*Malus domestica* Borkh.), as it reduces the need for pruning (Greene 1999; Owens and Stover 1999; Guak et al. 2001; Byers et al. 2004; Medjdoub et al. 2004, 2005). ProCa may also affect the generative growth; it has increased the fruit number in apple (Greene 1999, 2007; Glenn and Miller 2005) and pear (*Pyrus communis* L.) (Smit et al. 2005), and berry yield in strawberry (*Fragaria* × *ananassa* Duch.) (Hytönen et al. 2008). In apple, increased fruit set was primarily caused by a reduced abscission during June drop (Greene 2008). On the other hand, when grapevine (*Vitis vinifera* L.) was treated with ProCa before bloom, growth was reduced, but a substantial crop loss also occurred (Lo Giudice et al. 2003).

Our earlier study demonstrated that in primocane-fruiting raspberry 'Ariadne' repeated applications of ProCa reduced cane height by 29 to 41 % (Palonen and Mouhu 2009). At the same time, however, a large part of crop potential was lost, since in all ProCa treated plants the number of flowers was reduced by 22 to 42 %. Yolla Ghora et al. (2000) also studied the effect of different growth retardants on plant height and fruiting of 'Autumn Bliss', a primocane-fruiting cultivar. Flower initiation in primocane-fruiting raspberries occurs early in the season, at a time when canes are actively elongating (Carew et al.

2000). Therefore, the effects of ProCa treatment on vegetative and generative development can not be separated. In biennial-fruiting cultivars cane elongation and flower initiation are temporally separated. Therefore, it might be possible to control vegetative growth of biennial-fruiting raspberry cultivars without affecting floral development and crop potential. The aim of this study was to examine the effect of single and repeated ProCa treatments on vegetative growth and crop potential of 'Glen Ample' and 'Tulameen' biennial fruiting raspberry cultivars.

Materials and Methods

Plant material and treatments

The experiment was performed at the University of Helsinki experimental field and greenhouse in Viikki, Finland (60° 13' 41 N, 25° 01' 17 E). Red raspberry (*Rubus idaeus* L.) plants 'Glen Ample' established from root buds were received in spring 2004 from a commercial nursery (Marja-Suomen Taimituotanto Oy, Suonenjoki, Finland) and planted in 3.5-L pots in peat-based growing mixture (Kekkilä Oyj, Tuusula, Finland). Plants were grown outdoors during summer and cold stored at 1 °C until 18 May 2005, when they were transferred outside. Primocanes that had initiated growth in cold storage, were pruned to soil level. 'Tulameen' plants were propagated in February 2004 at the Swedish Elite Plant Station (Elitplantstationen, Balsgård, Kristianstad, Sweden), pruned down in the fall and cold stored. They were received on 2 May, 2005 in dormant condition, transplanted in 3.5-L pots in peat-based growing mixture and transferred outside on 9 May. The plants were grown outside during summer and drip-irrigated with a complete fertilizer solution (NPK 12-5-27, conductivity 1.0 mS cm^{-1}). One primocane per pot was allowed to grow and trellised in horizontal wires.

As the weather in May and the beginning of June was exceptionally cold, plant growth was slow and ProCa treatments could be started only at the end of June. There were six treatments in the experiment, as shown in Table 1. The plants were randomly assigned to different treatments and there were 25 single plant replicates for 'Glen Ample' and 20 single plant replicates for 'Tulameen'. BAS 125 10 W (a.i. 10 % w/w ProCa) was diluted in ultra-pure water, so that the concentration was either 100 or 200 ppm in different treatments. The plants were sprayed with a hand sprayer until drip off inside a fume hood. Control plants were sprayed with ultra-pure water. After the treatments, the plants were set on the experimental field in random order. When treated for the first time on 21 June, 'Tulameen' plants were 26 cm in height and had 10 leaves, as an average. 'Glen Ample' plants were first treated on 28 June, when they were 18 cm in height and had 10 leaves, as an average. Half of the plants were subjected to a second ProCa application four weeks later.

Observations on primocane growth

Primocane height and diameter (1 cm above soil level) were measured and the number of leaves was recorded before the first ProCa treatment. Thereafter, cane height and the number of new leaves were recorded weekly until 23 August and in two- or three-week-intervals thereafter until the end of September. Cane diameter (1 cm above soil level) was measured again at the end of the growing season on 25 October, when plants were moved into cold storage (5 °C, RH 50 %). Leaves in 'Glen Ample' plants were still green, and only half of them had abscised. In contrast, most of the leaves in 'Tulameen' had abscised.

Observations on floricane growth

Plants were cold stored at 5 °C for 71 d until greenhouse forcing was initiated on 4 January, 2006. Thus, they accumulated 1700 chilling hours, which should be sufficient for dormancy release in these cultivars (White 1999). During forcing, photoperiod was 15 h, average light intensity 1 m above the level of pots 263 $\mu molm^{-2} s^{-1}$ (SON-T 400 W, Philips), and temperature 20/19 °C (day/night). To even out light conditions, greenhouse compartment was divided into six subcompartments using white plastic film. Fifteen plants per treatment were randomly divided into the subcompartments each consisting

Table 1. Raspberry cultivars 'Glen Ample' and 'Tulameen' were subjected to different ProCa treatments.

Treatment name	Treatment	Date	
		'Glen Ample'	'Tulameen'
Control 1	Water	28 June	21 June
ProCa 100	ProCa 100 ppm	28 June	21 June
ProCa 200	ProCa 200 ppm	28 June	21 June
Control 2	2 × water	28 June and 26 July	21 June and 19 July
ProCa 100+100	2 × ProCa 100 ppm	28 June and 26 July	21 June and 19 July
ProCa 200+200	2 × ProCa 200 ppm	28 June and 26 July	21 June and 19 July

of two rows with 15 sample plants. Plants were drip-irrigated with a complete fertilizer solution (NPK 7-4-27 and NPK 14-0-38 in proportion 1:1, conductivity 0.5 mS cm^{-1} during January and 1.0 mS cm^{-1} thereafter). Root suckers were removed. During forcing, leaves in some plants turned yellow and finally these plants died. Therefore, two 'Glen Ample' and eight 'Tulameen' plants had to be discarded.

In the beginning of forcing the number of buds in the canes was recorded. Number of broken buds was recorded twice a week during January and weekly thereafter. To estimate crop potential, the number of flowers in each lateral shoot was recorded weekly from 3 February until 31 March. On the last observation date, the unbroken flowers were also included. When finishing the experiment (5 to 6 April 'Tulameen' and 10 to 11 April 'Glen Ample'), the length of the lateral shoots was measured and the number of nodes in lateral shoots was recorded. Dry weight of a cane and vegetative parts of lateral shoots, separately, was determined (73 °C, 7 to 9 d).

The experimental design was a completely randomized design (CRD) with 13 to 25 single plant replicates in different observations. The number of replicates varied, since after the first year five 'Glen Ample' plants were harvested for the carbohydrate analyses (data not shown), and during forcing some plants had to be discarded. Data were subjected to analysis of variance to determine treatment effects using SPSS (SPSS Inc.). Treatment means were separated using Dunnett's test.

Results

Primocane growth

ProCa treatments reduced primocane height and dry weight in both cultivars (Table 2). In 'Glen Ample', elongation of primocanes was reduced in repeat treatments (ProCa 100+100 and ProCa 200+200) by 25 and 28 cm, respectively, compared to control. Growth in cane diameter was only affected by the repeated application of 200 ppm ProCa. The reduction in cane dry weight was 18 % in the plants treated twice with 100 ppm ProCa and 26 % in plants treated twice with 200 ppm ProCa. In 'Tulameen' same treatments reduced cane growth by 7 to 15 cm and the treatment ProCa 200 by 6 cm. Cane dry weight was reduced by 19 % in the treatment ProCa 200+200.

In both cultivars, cane growth resumed after the initial reduction in growth following the first ProCa treatment, and in 'Tulameen' even after the second treatment (Fig. 1). 'Glen Ample' ceased growing earlier in the fall, and growth did not resume after the second treatment in this cultivar. New internodes in the treated 'Glen Ample' plants were shorter than in the control plants for two weeks after the first ProCa application and for four and six weeks after the second application in ProCa 100+100 and ProCa 200+200, respectively (Fig. 2B). Three weeks after the first application in ProCa 200+200, 'Glen Ample' internodes grew longer in the treated plants compared to

Table 2. Primocane growth as affected by different ProCa treatments in two raspberry cultivars. Values are means for 21 to 25 single plant replicates ('Glen Ample') or 15 to 19 single plant replicates ('Tulameen'). Means marked with an asterisk are different from a corresponding control at $P \leq 0.05$ (*) or at $P \leq 0.001$ (***) by Dunnett's test.

Treatment	Growth in height (cm)	Growth in diameter (mm)	Cane dry weight (g)	Number of nodes $cane^{-1}$	Internode length (cm)
'Glen Ample'					
Control 1	82	4.3	19.2	34	3.0
ProCa 100	79	4.1	19.7	34	2.9
ProCa 200	77	4.6	20.1	34	2.8*
Control 2	81	4.8	18.8	33	3.0
ProCa 100+100	56***	4.4	15.5*	31*	2.4***
ProCa 200+200	53***	3.9*	13.9***	31*	2.3***
P-value	< 0.001	ns.	< 0.001	< 0.001	< 0.001
'Tulameen'					
Control 1	109	2.9	22.7	46	3.0
ProCa 100	107	3.0	22.1	47	2.8***
ProCa 200	103*	2.9	23.5	47	2.8***
Control 2	106	3.1	21.2	46	2.9
ProCa 100+100	99*	3.0	20.0	46	2.7***
ProCa 200+200	91***	2.5	17.2*	44	2.6***
P-value	< 0.001	ns.	< 0.001	ns.	< 0.001

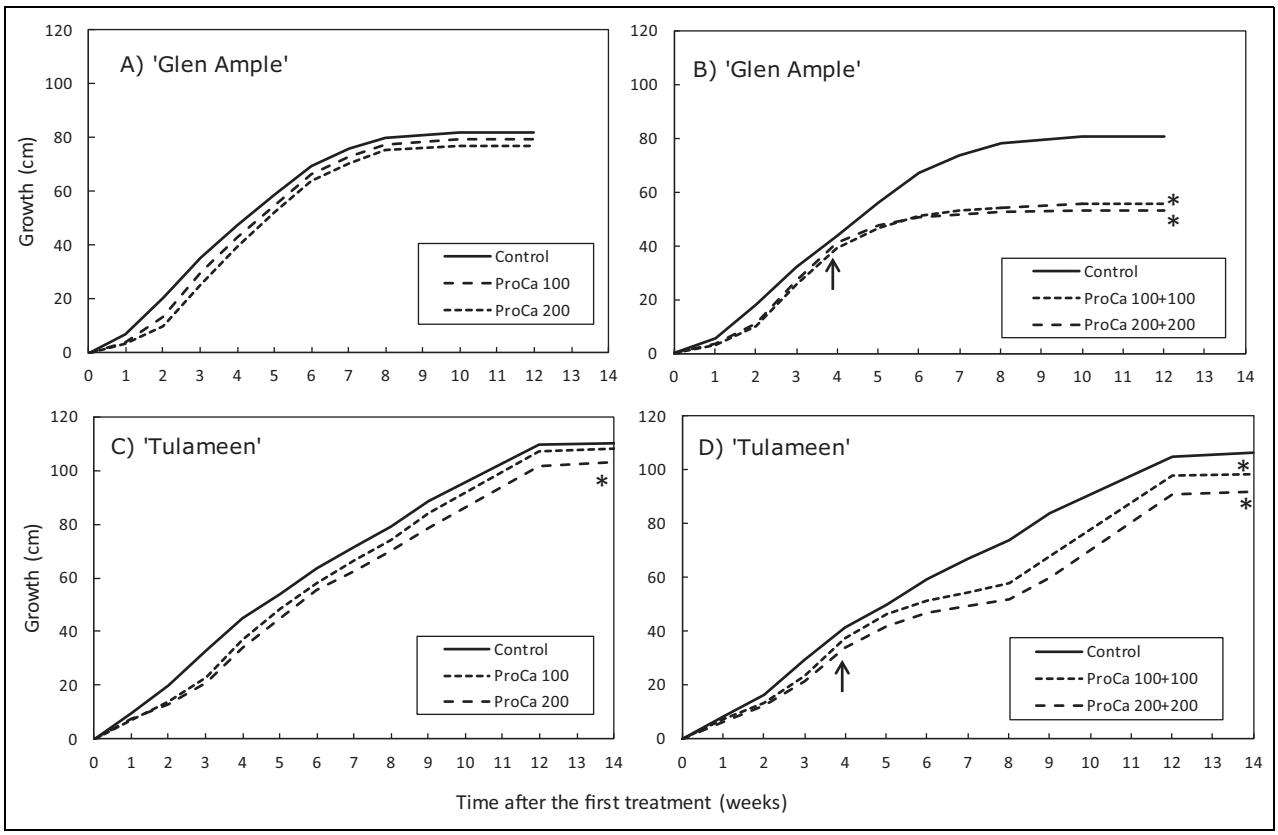


Fig. 1. Cane growth of two raspberry cultivars as affected by different ProCa treatments. Arrows indicate the time of the second ProCa application. Final values marked with an asterisk (*) are different from a corresponding control at $P \leq 0.05$ by Dunnett's test. (n = 21 to 25 for 'Glen Ample', n = 15 to 19 for 'Tulameen').

control. New internodes in the treated 'Tulameen' plants were shorter when measured one week and three weeks after the first application in ProCa 100, and for three weeks after the first application in ProCa 200 (Fig. 2C). In repeat treatment ProCa 200+200, new internodes were shorter, when measured two and three weeks after the first application and two to four weeks after the second application (Fig. 2D). Five weeks after the ProCa application in the 'Tulameen' plants treated once and eight weeks after the second application in the plants treated twice internodes grew longer than in the controls. In 'Glen Ample' single ProCa application had no effect on node number, but the plants treated twice had fewer nodes compared to control (Table 2). The average internode length was shorter in ProCa 200 and in the plants treated twice with ProCa than in the control plants. In 'Tulameen' total node number in plants was not affected by the treatments. However, the average internode length was reduced in all the treated 'Tulameen' plants.

Floricane growth and crop potential

After dormancy release in cold storage the proportion of bud break in greenhouse forcing ranged between 41 and 46 % in 'Glen Ample', and between 41 and 47 % in 'Tulameen' (Table 3). It was not affected by the treatments in either of the cultivars. In 'Glen Ample', bud break was delayed in the plants treated twice with ProCa. The proportion of broken buds in these plants was reduced by 24 to 29 % during days 8 to 15 from the beginning of forcing. Regardless of the treatment, bud break in the lower parts of the canes was delayed compared to the upper parts. However, the total number of broken buds in 'Glen Ample' was reduced only by the treatment ProCa 100+100 (Table 3). Furthermore, the number of floral buds and the proportion of floral buds of all broken buds were reduced by repeat applications of ProCa. More buds broke in 'Tulameen' than in 'Glen Ample', but the proportion of floral buds of all buds was lower. ProCa treatments had no effect on the number of broken buds or floral buds, nor on the proportion of floral buds in 'Tulameen'.

The onset of flowering was observed 30 d from the beginning of forcing in both cultivars (Fig. 3). In 'Glen Ample', flowering proceeded in two flushes being delayed in lower parts of the canes. Repeat applications of ProCa also delayed flowering; the number of flowers during days 33 to 65 from the beginning of forcing was reduced by 29 to 44 %. Later, the differences disappeared, and the total flower number was not affected by ProCa treatments in either of the cultivars. The average

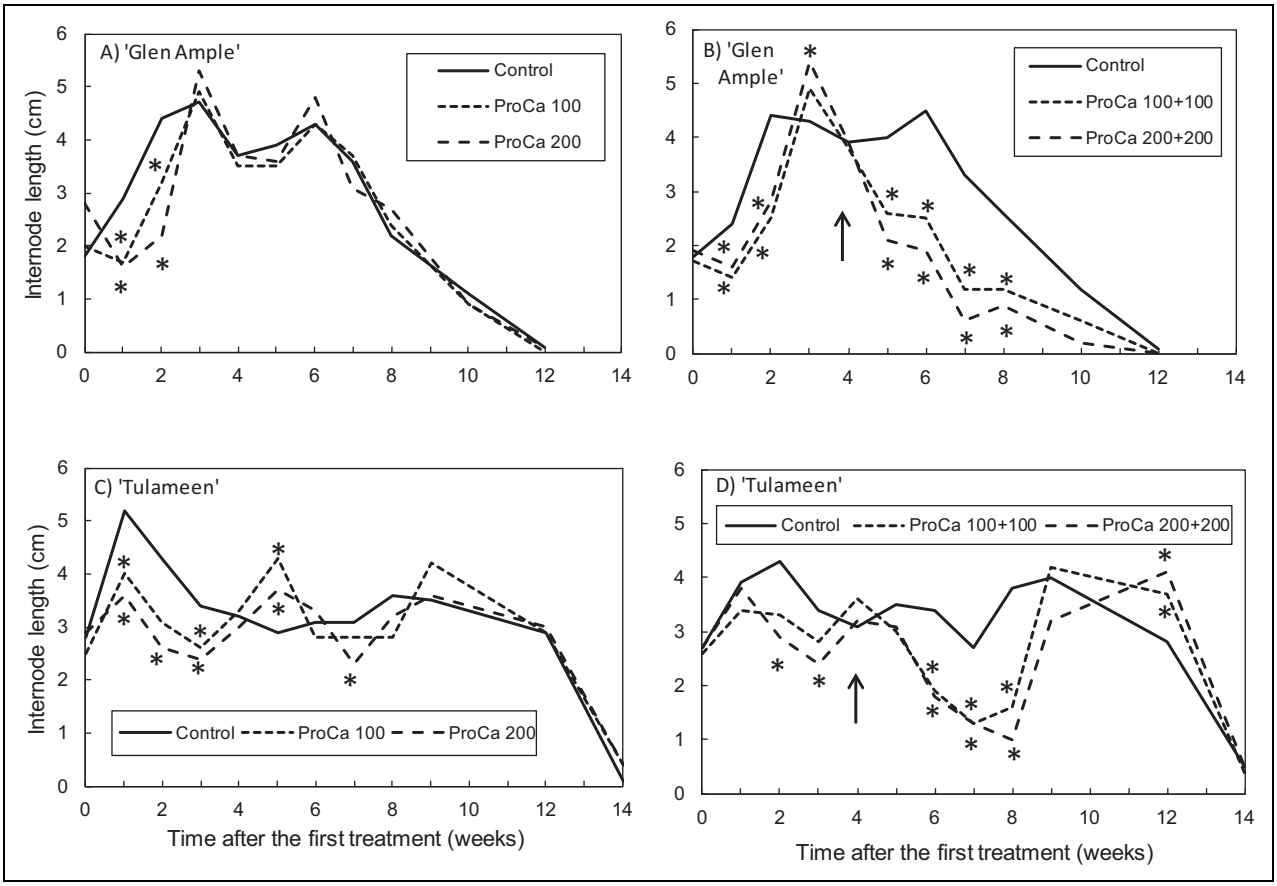


Fig. 2. The length of the newly developed internodes in primocanes of two raspberry cultivars treated either once (A, C) or twice (B, D) with ProCa. Arrows indicate the time of the second ProCa application. Values marked with an asterisk (*) are different from a corresponding control at $P \leq 0.05$ by Dunnett's test. (n = 21 to 25 for 'Glen Ample', n = 15 to 19 for 'Tulameen').

number of flowers per cane in different treatments was 108 to 124 in 'Glen Ample', and 85 to 105 in 'Tulameen'. Crop potential (total number of flowers and flower buds that had not yet come into flower) ranged from 112 to 134 flowers cane^{-1} in 'Glen Ample', and from 92 to 113 flowers cane^{-1} in 'Tulameen', and was not affected by the treatments.

The number of lateral shoots in 'Glen Ample' was reduced but their length was increased by repeat applications of ProCa (Table 3). In 'Tulameen' only the treatment ProCa 100 reduced slightly the number of lateral shoots. Their length was not affected. Total dry weight or internode length of lateral shoots were not affected by the treatments in either of the cultivars. Internode length was between 2.6 and 3.0 cm in 'Glen Ample' and between 2.3 and 2.4 cm in 'Tulameen'.

Discussion

Vegetative growth in primocanes of biennial-fruiting raspberry cultivars 'Glen Ample' and 'Tulameen' was reduced by ProCa treatments. The response was cultivar dependent being more pronounced in 'Glen Ample'. Furthermore, the effect of treatment concentration (100 or 200 ppm) was minor when compared to the effect of repeating the treatment. As growth resumed already two to three weeks after the first application, repeated treatments were necessary to achieve permanent reduction in cane height. In 'Glen Ample' primocane growth ceased when ProCa was still effective, whereas in 'Tulameen', growth continued after the effect of the second ProCa application had finished. A third ProCa application would have been useful to prevent growth resumption of 'Tulameen'. Although repeated treatments reduced node number in 'Glen Ample' canes by two, the main influence of ProCa was that it shortened the internodes. This agrees with earlier reports (Lo Giudice et al. 2003; Medjdoub et al. 2004, 2005; Palonen and Mouhu 2009). In 'Glen Ample' treatment ProCa 200+200 reduced primocane dry weight by about one fourth. Medjdoub et al. (2005) observed 30 to 51 % reduction in dry weight of apple shoots treated twice with ProCa.

Table 3. Number of broken buds and floral buds, and the number, length and dry weight of the lateral shoots in floricanes of two raspberry cultivars subjected to different ProCa treatments. Values are means for 13 to 15 single plant replicates. Means marked with an asterisk are different from a corresponding control at $P \leq 0.05$ (*) or at $P \leq 0.001$ (***) by Dunnett's test.

Treatment	Number of broken buds cane^{-1}	Number of floral buds cane^{-1}	Number of lateral shoots cane^{-1}	Length of lateral shoots (cm)	Lateral shoot dry weight cane^{-1} (g)
'Glen Ample'					
Control 1	12.0	10.1	10.5	20.0	15.5
ProCa 100	11.5	10.8	11.4	21.8	17.5
ProCa 200	12.5	11.0	11.4	20.6	17.1
Control 2	12.5	11.5	11.7	19.0	15.7
ProCa 100+100	9.5*	7.5***	7.9***	24.5*	17.0
ProCa 200+200	10.3	7.6***	8.5***	27.2***	19.3
P-value	0.004	< 0.001	< 0.001	< 0.001	ns.
'Tulameen'					
Control 1	18.4	11.7	13.1	18.9	25.6
ProCa 100	16.9	11.9	11.1*	18.8	23.7
ProCa 200	18.7	11.9	12.4	19.4	25.9
Control 2	15.5	10.6	11.2	19.2	23.7
ProCa 100+100	17.5	10.4	11.2	19.9	24.9
ProCa 200+200	17.5	10.2	10.7	19.0	23.8
P-value	ns.	ns.	0.019	ns.	ns.

According to Greene (1999), ProCa starts to be effective 10 to 14 d after the application in apple. In raspberry the response was observed already one week after the application. The plants produced shorter internodes for two or three weeks after the first, and for four weeks after the second application. In ProCa treated strawberry, the level of active GA_1 decreases by 50 % in 1 d and by 75 % in 4 d (Hytönen et al. 2009).

Since ProCa breaks down rapidly in a plant, both timing and number of applications are crucial for successful growth control (Evans et al. 1999; Medjdoub et al. 2004, 2005). 'Glen Ample' plants produced longer internodes than the control plants three weeks, and 'Tulameen' plants five or eight weeks after the ProCa application. Similar response has been observed in strawberry nine weeks after ProCa application (Reekie and Hicklenton 2001). Growth may be more vigorous than normal growth, because after breakdown of ProCa accumulated precursors of active gibberellin are converted into the active form, and excess gibberellin is available in a plant (Evans et al. 1999). In strawberry, repeated ProCa applications in three-week-intervals are necessary to control plant height (Reekie and Hicklenton 2001). Likewise, ProCa applications in three-week-intervals were found necessary for growth control of primocane-fruiting raspberry (Palonen and Mouhu 2009). According to Medjdoub et al. (2004), apple trees should be treated twice in 6 to 8 weeks interval to avoid regrowth of the shoots.

Possible influence of ProCa on winter hardiness should also be taken into account. If applied in the fall, ProCa may advance growth cessation (Owens and Stover 1999) and thereby possibly enhance winter hardiness. Although ProCa advanced terminal bud set in 'Muskoka' raspberry, winter hardiness of the plants was not improved (Palonen et al. 2009). On the other hand, excess gibberellin following ProCa treatment may delay growth cessation and cold acclimation leading into decreased winter hardiness. Elfving et al. (2002) concluded that excess GA_1 caused by breakdown of ProCa enhanced growth of pear still in the growing season following ProCa application.

Presumably, 1700 hours of chilling was not sufficient to release endodormancy. In both cultivars, but more pronounced in 'Glen Ample', bud break in the base of the canes was delayed. Less than half of the buds broke during forcing. Poor bud break in 'Glen Ample' has been observed before (White 1999). The accumulated chilling hours in our experiment should have been enough to release endodormancy. However, White et al. (1998) have stated that buds on the lower parts of a raspberry cane remain in the paradormant state after endodormancy release and further chilling is needed to remove this condition.

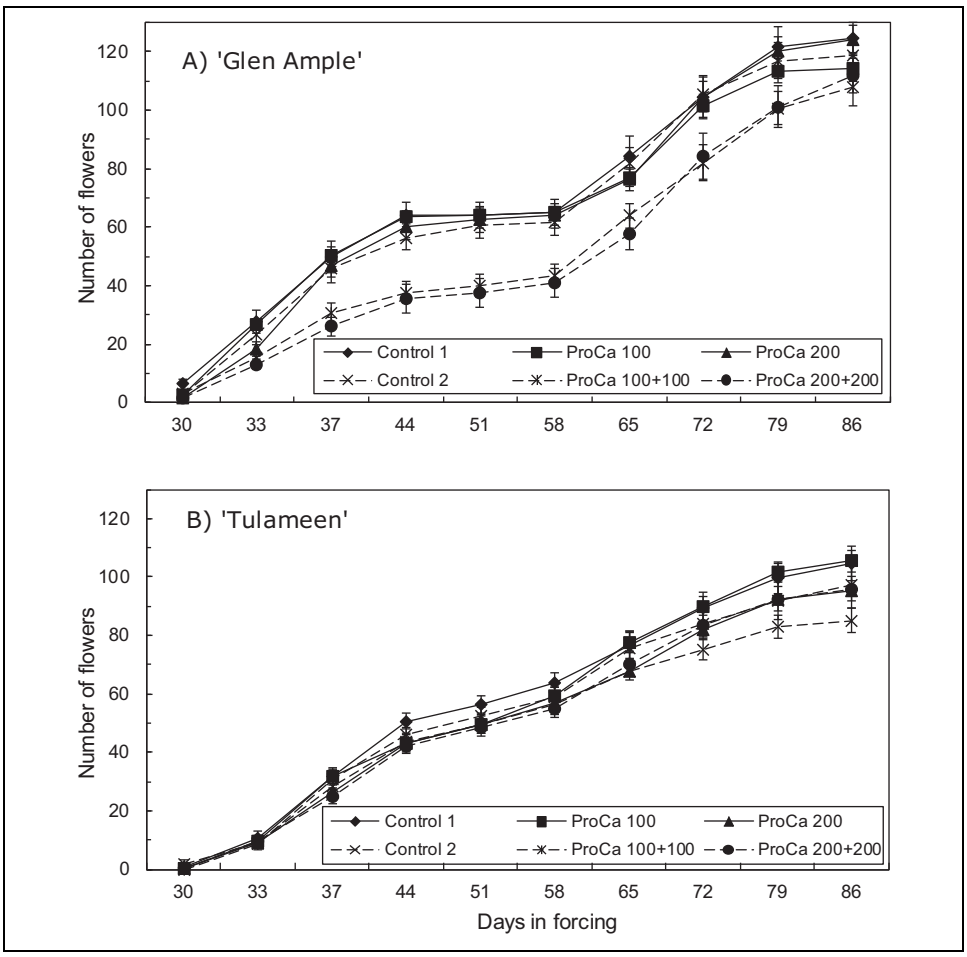


Fig. 3. Cumulative number of flowers during forcing in two raspberry cultivars as affected by different ProCa treatments. Vertical bars present ± SE. (n = 15 for 'Glen Ample', n = 13 to 15 for 'Tulameen').

Changes in GA metabolism following ProCa treatments may have interfered with generative development of raspberry. Although the total flower number in plants was unaffected, repeated ProCa applications reduced number of flower buds and delayed flowering in 'Glen Ample'. Growth cessation and floral initiation in raspberry coincide in time, as they are controlled by same environmental conditions (Sønsteby and Heide 2008). During growth cessation of 'Glen Ample', probably excess GA_1 caused by breakdown of ProCa was available in a plant. GAs play a role in flower induction and applied GAs may inhibit flower bud development (Hoad 1984). In biennial-fruiting raspberry, number of flowers was reduced, when plants were treated with GA in August after harvest (Maage 1986). On the other hand, in primocane-fruiting raspberry increased GA levels in the shoot tip are associated with flower induction (Vasilakakis et al. 1979). Sugar et al. (2004) concluded that reduction in return bloom following ProCa treatment in the biennial-bearing prone pear cultivars was caused by suppression of flower bud formation by GAs. Thus, for raspberry, the last ProCa application should be relatively late to avoid growth resumption in the fall. On the other hand, this last application should be made so early that it does not disturb flower induction or initiation. Further research is also needed to understand the role of gibberellins in raspberry flower induction.

In conclusion, as ProCa was effective in reducing vegetative growth of primocanes without affecting crop potential, it may become useful in growth control of biennial-fruiting raspberry cultivars. Shorter canes with shorter internodes may facilitate trellising and harvest without sacrificing flower buds for pruning. However, the timing and number of ProCa applications is extremely crucial and warrants further research.

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References

Byers, R.E., D.H. Carbaugh and L.D. Combs 2004: The influence of prohexadione-calcium sprays on apple tree growth, chemical fruit thinning, and return bloom. J. Amer. Pomol. Soc. **58**, 111–117.

Carew, J.G., T. Gillespie, J. White, H. Wainwright, R. Brennan and N.H. Battey 2000: The control of annual growth cycle in raspberry. J. Hortic. Sci. & Biotech. **75**, 495–503.

Elfving, D.C., D. Sugar and D. Faubion 2002: Pear tree shoot growth patterns in relation to chemical control of vegetative growth with Prohexadione-Calcium (Apogee®). Acta Hort. **596**, 711–716.

Evans, J.R., R.R. Evans, C.L. Regusci and W. Rademacher 1999: Mode of action, metabolism, and uptake of BAS 125W, prohexadione-calcium. HortScience **34**, 1200–1201.

Glenn, D.M. and S.S. Miller 2005: Effects of Apogee on growth and whole-canopy photosynthesis in spur 'Delicious' apple trees. HortScience **40**, 397–400.

Greene, D.W. 1999: Tree growth management and fruit quality of apple trees treated with prohexadione-calcium (BAS 125). HortScience **34**, 1209–1212.

Greene, D.W. 2007: The effect of prohexadione-calcium on fruit set and chemical thinning of apple trees. HortScience **42**, 1361–1365.

Greene, D.W. 2008: The effect of repeat annual applications of prohexadione-calcium on fruit set, return bloom, and fruit size in apple. HortScience **43**, 376–379.

Guak, S., D. Neilsen and N.E. Looney 2001: Growth, allocation of N and carbohydrates, and stomatal conductance of greenhouse grown apple treated with prohexadione-Ca and gibberellins. J. Hortic. Sci. & Biotech. **76**, 746–752.

Hoad, G.V. 1984: Hormonal regulation of fruit-bud formation in fruit trees. Acta Hort. **149**, 13–23.

Hytönen, T., K. Mouhu, I. Koivu and O. Junttila 2008: Prohexadione-calcium enhances the cropping potential and yield of strawberry. Europ. J. Hort. Sci. **73**, 210–215.

Hytönen, T., P. Elomaa, T. Moritz and O. Junttila 2009: Gibberellin mediates daylength-controlled differentiation of vegetative meristems in strawberry (*Fragaria* × *ananassa* Duch). BMC Plant Biology **9**, 18.

Lo Giudice, D., T.K. Wolf and R.P. Marini 2003: Vegetative response of *Vitis vinifera* to Prohexadione-calcium. HortScience **38**, 1435–1438.

Maage, F. 1986: Growth responses and physiological studies in red raspberry plants treated with growth regulators. Acta Hort. **183**, 291–296.

Medjdoub, R., J. Val and A. Blanco 2004: Prohexadione-Ca inhibits vegetative growth of 'Smoothee Golden Delicious' apple trees. Scientia Hort. **101**, 243–253.

Medjdoub, R., J. Val and A. Blanco 2005: Inhibition of vegetative growth in red apple cultivars using prohexadione-calcium. J. Hortic. Sci. & Biotech. **80**, 263–271.

Owens, C.L. and E. Stover 1999: Vegetative growth and flowering of young apple trees in response to prohexadione-calcium. HortScience **34**, 1194–1196.

Palonen, P. and K. Mouhu 2009: Vegetative growth and flowering of primocane raspberry 'Ariadne' as affected by prohexadione-calcium treatments. HortScience **44**, 529–531.

Palonen, P., E. Pehkonen and M. Rantanen 2009: Vegetative growth, cropping and winter hardiness of selected raspberry cultivars as affected by ProCa. Acta Hort. **838**, 99–102.

Reekie, J.Y.-C. and P.R. Hicklenton 2001: Strawberry growth response to prohexadione-calcium. Strawberry research to 2001. Proceedings of the 5th North American Strawberry Conference **5**, 147–152.

Smit, M., J.J. Meintjes, G. Jacobs, P.J.C. Stassen and K.I. Theron 2005: Shoot growth control of pear trees (*Pyrus communis* L.) with prohexadione-calcium. Scientia Hort. **106**, 515–529.

Sugar, D., D.C. Elfving and E.A. Mielke 2004: Effects of prohexadione-calcium on fruit size and return bloom in pear. HortScience **39**, 1305–1308.

Sønsteby, A. and O.M. Heide 2008: Environmental control of growth and flowering of *Rubus idaeus* L. cv. 'Glen Ample'. Scientia Hort. **117**, 249–256.

Vasilakakis, M.D., B.H. McCown and M.N. Dana 1979: Hormonal changes associated with growth and development of red raspberries. Physiol. Plant. **45**, 17–22.

White, J.M., H. Wainwright and C.R. Ireland 1998: Interaction of endodormancy and paradormancy in raspberry (*Rubus idaeus* L.). Ann. Appl. Biol. **132**, 487–495.

White, J.M. 1999: Factors influencing the control of dormancy and bud break in raspberry (*Rubus idaeus* L.). Ph.D. thesis. Department of Horticulture, Writtle College, University of Essex, UK.

Yolla Ghora, M. Vasilakakis and G. Stavroulakis 2000: Effect of growth retardants (cyclocel, daminozide and paclobtrazol) on growth and development of red raspberries, cv. 'Autumn Bliss', cultivated under plastic greenhouse conditions in Chania-Crete, Greece. Acta Hort. **513**, 453–458.

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