Canadian Journal of Plant Science
Revue canadienne de phytotechnie

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Journal:	<i>Canadian Journal of Plant Science</i>
Manuscript ID	CJPS-2016-0314.R2
Manuscript Type:	Article
Date Submitted by the Author:	14-Dec-2016
Complete List of Authors:	Cline, John; University of Guelph Ontario Agricultural College, Plant Agriculture
Keywords:	apple, Promalin, Malus domestic, russet, typiness

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Interactive effects of 6-BA, GA₄₊₇ and prohexadione-calcium on 'Gala' apples

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ABSTRACT

Gibberellic acid (GA₄₊₇) and the cytokinin 6-benzyladenine (6-BA) are used during bloom and fruit set to reduce russetting and improve typiness of select apple cultivars. The gibberellin synthesis inhibitor, prohexadione-calcium (P-Ca), is used at the same developmental stage to reduce vegetative growth and susceptibility to fireblight. The use of GA₄₊₇/6-BA for enhancing typiness of 'Gala' and the interaction of GA₄₊₇/6-BA and P-Ca was investigated in a two-year experiment on mature 'Royal Gala'/Bud.9 trees. Six treatments were imposed: i) untreated control; ii-iv) 5.5, 11 and 21 mg L⁻¹ each of GA₄₊₇ and 6-BA; v) 123 mg L⁻¹ P-Ca, and; vi) a tank mix of 21 mg L⁻¹ GA₄₊₇/6-BA and 123 mg L⁻¹ P-Ca. Trees treated with P-Ca had 21-45% less growth than the untreated trees or trees treated with GA₄₊₇/6-BA. In one of two years, the addition of GA₄₊₇ and 6-BA tank-mixed with P-Ca reduced the efficacy of P-Ca on shoot growth. GA₄₊₇/6-BA decreased soluble solids and fruit firmness in one year, suggesting a delay in fruit maturity. P-Ca alone reduced scarf skin by 7-10%; however, this effect was negated when combined with GA₄₊₇ plus 6-BA in one of the two years. GA₄₊₇ plus 6-BA increased fruit typiness and length:diameter ratios.

Key words: apple, Promalin, *Malus domestica*, russet, typiness

Abbreviations: 6-BA- 6-benzyladenine, GA₄₊₇- gibberellic acid, L:D – length/diameter ratio, NAA – naphthalene acetic acid, PGRs – plant growth regulators, P-Ca - prohexadione-calcium, PF – petal fall, TCSA – trunk cross-sectional area, TRV – tree row volume

INTRODUCTION

Plant growth regulators (PGRs) are widely used in tree fruit production for varying purposes ranging from fruitlet thinning apples to regulating vegetative growth and fruit maturity. During bloom, gibberellic acid (GA₄₊₇) is used to reduce skin russet and improve skin finish (Curry, 1990; Leite et al, 2005; Taylor, 1975). The cytokinin 6-benzyladenine (6-BA) is also used at petal fall (PF) and four weeks following PF to improve the typiness of 'Red Delicious' apples (Williams, 1983). At this same developmental stage, the gibberellin synthesis inhibitor prohexadione-calcium (P-Ca) is used on apples to reduce vegetative growth (Cline, 2005) and tree susceptibility to fireblight (*E. amylovora*) (Rademaker et al, 2006).

Currently, a mixture of 6-BA and GA₄₊₇ for improved typiness of apples is registered only on 'Red Delicious' in Canada under the commercial name Promalin® (Valent BioScience Canada, Ltd) and Perlan® (Fine Americas Ltd., Worcester, UK). These products increase the length:diameter (L:D) ratio through elongation of fruit and the development of more prominent calyx lobes. There is industry interest to expand the

product label of Promalin® in Canada to include other cultivars such as 'Gala'. However, product efficacy must first be demonstrated through evidence-based field studies as a requirement for a change in use pattern (to include other cultivars) by the federal body overseeing pesticide use, the Pest Management Regulatory Agency (Anonymous, 2003).

Single or repeat application of P-Ca is/are used on apples from bloom throughout the vegetative growth period (up to 8 weeks after bloom) to reduce shoot elongation (Cline, 2005). P-Ca has been associated with increased fruit set in apple trees when applied at PF at 125 or 250 mg·L⁻¹ (Greene, 2007). When carbaryl or naphthalene acetic acid (NAA) chemical thinners were applied before, at the time of, and after application of P-Ca, they did not reduce fruit set to the same crop load level as they did on untreated trees (Greene and Lord, 1985). The authors concluded that a different and more aggressive chemical thinning strategy must be considered on trees that were pre-treated with P-Ca. Evidence in the literature to support the notion that P-Ca increases fruit set is conflicting. For example, several reports document increased fruit set with the use of P-Ca (Byers et al. 2004; Glenn and Miller, 2005; Greene, 1999), while others report no effect on fruit set and/or yield (Byers and Yoder, 1999; Costa et al. 2000; Miller, 2002; Petri et al, 2010).

There are few studies that have investigated the interaction of P-Ca used for vegetative growth control, and 6-BA and GA₄₊₇ used for management of fruit russet or for improved fruit typiness. In a study on 'Golden Delicious', a cultivar prone to russetting, McArtney et al. (2007) observed that a single application of 138 to 167 mg·L⁻¹ P-Ca at PF reduced the severity of russet in three of four experiments. However,

multiple applications of 20 mg.L^{-1} GA_{4+7} at 10-day intervals beginning at PF reduced russet more effectively than P-Ca. P-Ca did not reduce the efficacy of GA_{4+7} sprays for russet reduction but GA_{4+7} sprays did reduce the inhibitory effects of P-Ca on shoot growth. Miller (1988) reported that GA_{4+7} sprays to reduce russet in 'Golden Delicious' diminished shoot growth control normally obtained with P-Ca. P-Ca also reduced russet but decreased the efficacy of GA_{4+7} sprays for the control of scarf skin.

Studies on the interaction of GA_{4+7} and P-Ca on 'Gala' apples have not been reported in the literature. More specifically, the interacting effects of GA_{4+7} plus 6-BA used at PF for fruit typiness and P-Ca applied at the same time for vegetative growth control is of interest given the opposing physiological basis in which these GA-promoting and inhibiting compounds work. We hypothesize that the effect of P-Ca (e.g., Apogee™) can be negated by the use of 6-BA and GA_{4+7} (e.g., Promalin®). The objective of the following research was to determine the response of 'Royal Gala' apples to different rates of 6-BA and GA_{4+7} . A second objective was to measure the interaction of 6-BA, GA_{4+7} and P-Ca on the efficacy of P-Ca for shoot growth control.

MATERIALS AND METHODS

A mature research orchard of 'Gala'/Bud.9 rootstock located at the University of Guelph, Simcoe Campus ($42^{\circ}51'40''$ N Lat. $80^{\circ}16'8''$ W Long.), planted in 2002 at a spacing of $3.5 \text{ m} \times 2.5 \text{ m}$ ($1,143 \text{ trees ha}^{-1}$) was used for this study in 2010 and 2011. Trees were trickle irrigated with approximately 2.5 cm of water per week (adjusted for natural rainfall) on a schedule of 6 irrigation run times per day every four hours (20 mins per event) using 2 L. hr^{-1} pressure-compensating emitters spaced 45 cm apart and trained to

a vertical axe-supported training system. Standard cultural and pest management practices for Ontario were used (OMAFRA, 2010). The orchard soil was classified as a Brady sandy loam (Aquaic Hapludalf) with imperfect drainage and soil textures consisting of mainly lacustrine sand and sandy loam over glaciolacustrine clays. Weeds were controlled using 1% (v/v) glyphosate applications made mid-May, June, and July. A permanent sod culture was established in 2002 using a mixture of perennial rye, red fescue and Kentucky blue grass. Prior to this study, all trees were managed uniformly and were not subjected to any experimental treatments.

Treatments were applied using a commercial air blast sprayer (Model Laser P7; GB Irrorazione Diserbo, Italy) at 1,379 kPa, 1,941 L ha⁻¹, which equated to tree row volume (TRV) pesticide dilute (Sutton and Unrath, 1984). The sprayer was equipped with 5 nozzles per boom (side) and large axial fan to move the spray into the canopy. To minimize treatment interference caused by spray drift, experimental units were separated by at least one guard tree within the row. A randomized complete block design with five replications and four treatments was used as the experimental design. Blocking by replications was implemented to account for variation in soil type and potential difference in micro-climate (eg, air temperatures) down the tree row. Treatments were applied to a single rep of two trees per plot and consisted of: 1) untreated control; 2) 5.5 mg L⁻¹ each of GA₄₊₇ and 6-BA (Promalin; Valent Biosciences, Guelph, ON, Canada); 3) 11 mg L⁻¹ each of GA₄₊₇ and 6-BA; 4) 21 mg L⁻¹ each of GA₄₊₇ and 6-BA; 5) 123 mg L⁻¹ P-Ca (Apogee; BASF Canada Inc., Mississauga, ON, Canada); 6) a tank mix of treatments four and five. Agral 90 surfactant (Syngenta Canada Inc., Guelph, ON, Canada) at a rate of 0.05% (v/v) and ammonium sulfate (AMS) at a rate of

450 mg L⁻¹ were added to treatments five and six, as recommended by the manufacturer. Treatments were applied at PF on the morning of 5 May 2010 and 24 May 2011.

Municipal water (Norfolk County), derived from large ground wells in the region, was used as the source for the spray water. The water had an average pH ranging from 7.50 to 7.98 and hardness ranging of 281 to 295 mg L⁻¹ (K. Pressey, Personal Communication). The temperature of the water upon initial mixing in 2010 was 8.9°C, and in 2011 was 10.2°C. For each treatment, the sprayer was filled with 50% of the required water. The spray product was then added to the tank during agitation followed by the remaining balance of water (using a digital water meter to make up the final volume). The tank was agitated for at least 6 minutes prior to spraying. The spray mixture was clear and not foamy prior to spraying.

Tree trunk circumference 30 cm above the graft union was measured 17 Aug. 2010 and 24 Aug. 2011 and used to calculate trunk cross-sectional area. Trees were hand-thinned by singling clusters and spacing fruit ~15 cm apart on 30 June 2010, and 28 to 30 June 2011.

Due to the variability in ripening of 'Gala', fruit were harvested in two picks on the 10th and 17th of Sept. 2010, and on 21st Sept. and 4th Oct. 2010. All samples for fruit quality were harvested on 10 Sept. 2010 and 20 Sept. 2011. The total number and weight of fruit was recorded at each harvest, and a sample of approximately 60 fruit tree⁻¹ in 2010 and 100 fruit tree⁻¹ in 2011 was placed in cold storage (2-4°C, 80% RH) for subsequent grading on 22 Oct. 2010 and 21 Oct. 2011. Fruit were graded into 11 commercial weight categories (<86 g, 87 to 103 g, 104 to 120 g, 121 to 143 g, 144 to

159 g, 160 to 176 g, 177 to 193 g, 194 to 210 g, 211 to 233 g, 234 to 250 g, 251 to 266 g) which represented fruit diameters ranging from 57.2 to 88.9 mm in 3.2 mm increments.

In 2010, ten fruit per tree ranging in size from 69.8 to 82.5 mm (159 to 233 g) were used to determine fruit L:D ratio. This was achieved by measuring the total length and diameter of the ten fruit positioned longitudinally and then laterally in a 'V' trough, respectively. In 2011, the entire sample (~100 fruit) was used to determine the L:D ratio. Fruit density and volume were measured on each of the ~100 fruits per tree in 2011 using water displacement and a top-loading balance.

Mean fruit size was estimated by dividing the total mass of the marketable fruit by the number of fruit in the sample. Twelve sound fruit per two-tree plots were randomly selected to determine fruit colour, firmness, soluble solids, percent surface red colour, skin russet, stem-end cracking, and percent of the skin with scarf skin.

For each of the twelve fruit per experimental unit, the percent of the fruit surface with red blush was estimated visually person to the nearest 5%. Skin russet was rated on a 4-point scale, where 0, 1, 2, 3 represent no, slight, moderate, and severe russet, respectively. Fruit were also rated for presence or absence of stem-end cracking. Fruit were rated on the percentage of the fruit surface cover with scarf skin (to the nearest 5%) based on the presence of a white/milky colour overlaying red blush.

Fruit colour was recorded using a tri-stimulus colorimeter (Minolta CR-300; Konica Minolta Inc., Mississauga, ON, Canada) and recording colour on two opposite cheeks of the fruit. The instrument used D65 illuminant, an 11 mm viewing aperture and was calibrated using a near-white calibration plate (No. 2153303, $L^*=97.5$, $a^*=-0.02$,

$b^*=1.72$; Konica Minolta Inc., Mississauga, ON, Canada). After data acquisition, hue angle (h°) and Chroma C^* , an index somewhat analogous to colour saturation or intensity (Hunter 1942; Hunter Associates, 2008; Little 1975), was calculated according to methods published by McGuire (1992). Hue angle (h°), which represents the colour hue (i.e., concentration of blue, green, red, yellow components) was calculated from the arctangent of b^*/a^* . L^* represents lightness of color, ranging from complete darkness ($L = 0$) to pure white light ($L = 100$).

Fruit firmness was measured twice on each fruit using an electronic penetrometer (Fruit Texture Analyzer Model GS-14; Güss Manufacturing, Strand, South Africa). An 11 mm stainless steel diameter blunt probe was inserted at a rate of 5 mm sec^{-1} to a depth of 8.9 mm and the peak force was recorded. Measurements were taken on opposite sides of the fruit after a ~2 mm thick tangential section of peel (1.5 to 2.0 cm in diameter, 1 to 2 mm thickness) was sliced from the equator of the fruit. The mean of these two measurements was used in subsequent data analysis. Fruit soluble solids were measured using a temperature-compensating digital refractometer (model PR-100; Atago U.S.A. Inc., Bellevue, WA, U.S.A.) on juice extracted from 1/8th longitudinal sections of fruit extracted using a centrifugal juice extractor (Model Omega 9000; Omega Products Inc., Harrisburg, PA, U.S.A.). After measuring firmness, each apple was cut in half across the equator and the cut-end with the stem half was soaked in iodine solution for at least 5 minutes. The pattern of starch staining was compared to a reference chart (scale 1 to 8, where 1=100% core stained, 2=50% core stained, 3= 0% core stained, and 100 % flesh stained,... 8= no staining; no starch present) to determine the starch index (Blanpied and Silsby 1992).

Length of new growth on extension shoots was measured on a random sample of 10 shoots per tree between 1 and 2.5 m above the ground at two-week and four-week intervals in 2010 and 2011, respectively. Due to time limitations growth was measured on trees receiving treatments 1, 2, 5, and 6 only, excluding the 5.5 and 11 mg L⁻¹ GA₄₊₇ and 6-BA treatments.

Analysis of variance was conducted using the PROC GLM procedure of SAS (SAS Institute, Cary, N.C.). Duncan's Multiple Range test was used to separate treatment means ($P=0.05$). Percent data were arc-sine transformed prior to analysis to correct for heterogeneous variance (Snedecor, 1989). Non-transformed data are reported for means displayed in tables. Single degree of freedom orthogonal comparisons were performed to determine the significance of linear and quadratic rate responses to GA₄₊₇ plus 6-BA.

RESULTS AND DISCUSSION

Weather

The 2010 growing season was characterized as very warm with timely rains throughout the summer (Figure 1a). Daily maximum temperatures exceeded 30°C on several occasions, resulting in excellent fruit growth and a ~10-d advancement in fruit harvest. Two important weather-related events directly affected this experiment. First, bud phenology was advanced in early May due to an atypical warm spring culminating with five days with daily highs exceeding 20°C. Full bloom occurred on 2 to 3 May, approximately 10 d ahead of 'normal' for Simcoe. Second, following a rapid bloom period, PF occurred rapidly on 4 to 5 May, after a relatively short pollination period. This

coincided with the recommended (label) timing for the GA₄₊₇ plus 6-BA application; however, cooler unsettled weather was forecasted later in the week, resulting in less than ideal conditions for the application of GA₄₊₇ plus 6-BA. Consultation with the manufacturer led to the decision to proceed with the treatment applications on the morning of 5 May. Approximately 8 h following application, cooler unsettled weather persisted, with rain and air temperatures not exceeding 15°C for eight days (Figure 1b). On 10 May and 11 May, minimum temperatures fell below 0°C, resulting in frost damage to some cultivars at the Simcoe Research Station and local commercial orchards. However, the 'Royal Gala' trees and fruit in this experiment were not significantly affected by frost, as indicated by the reasonable (but below ideal) fruit set and absence of frost rings or misshapen fruit. However, the cool weather that persisted over this period would have reduced the activity of 6-BA and GA₄₊₇ and perhaps P-Ca within the tree. It is unlikely that plant uptake of GA₄₊₇ plus 6-BA was compromised, as air temperatures immediately following application exceeded 25°C and it was observed that the spray material adequately dried before the first rainfall event.

The 2011 growing season was similar in many respects to 2010, except that there was a greater frequency of days above 30°C and not the same concern over the cool weather following treatment applications. Analyses of growing degree days (base 5°C) did indicate that the 2011 growing season was 5% cooler than 2010 over the course of the growing season (data not shown). Bloom occurred 20 May 2011, with no frost events after this date (Figure 1c). Temperatures following the application of GA₄₊₇ plus 6-BA were conducive for uptake and physiological activity within the plant.

Tree Vigour, Yield and Fruit Size

There were no significant treatment effects on trunk cross-sectional area (TCSA), fruit weight, total number or yield per tree, crop load, or amount of pre-harvest fruit drop in either year of this study (Table 1). Orthogonal contrasts in 2010 indicated a linear increase in the number of fruit per tree (at harvest) with increasing GA₄₊₇ plus 6-BA concentrations ($P=0.0453$); however, this effect is confounded by the fact that fewer fruit were thinned at the “June drop” period when hand-thinning was performed (data not shown). There also appeared to be a slight but statistically significant linear increase in pre-harvest fruit drop with increasing concentrations of GA₄₊₇ plus 6-BA ($P=0.0337$), which did not coincide with advanced maturity of fruit treated with GA₄₊₇ plus 6-BA (Table 2). In 2011, orthogonal contrasts indicated a significant quadratic increase in total yield per tree with increasing concentrations of GA₄₊₇ plus 6-BA ($P=0.0392$).

Fruit Quality

There were no significant differences in soluble solids among the treatments in either year (Table 2). However, in 2010 regression analyses indicated a linear decrease in soluble solids with increasing rates of GA₄₊₇ plus 6-BA ($P=0.0568$), indicating that GA₄₊₇ plus 6-BA may have delayed fruit maturity.

In 2011, fruit from trees receiving 21 mg L⁻¹ GA₄₊₇ plus 6-BA were significantly firmer than fruit from the control trees or trees treated with 11 mg L⁻¹ GA₄₊₇ plus 6-BA ($P=0.003$), again indicating a delay in maturity mediated by GA₄₊₇ plus 6-BA or perhaps higher firmness as a result of increased cell division in response to the cytokinin 6-BA (Wismer et al. 1995). Results were inconsistent among treatments in 2011.

No treatment differences in the amount of skin russet was observed in either year, likely in part to low levels observed in the untreated control (Table 2). In 2010, orthogonal contrasts indicated that fruit from trees treated with P-Ca had significantly less red blush on the fruit surface compared to the controls; whereas, in 2011 fruit from trees treated with 22 mg L⁻¹ GA₄₊₇ plus 6-BA had significantly less red blush than those from trees treated with 5.5 mg L⁻¹ GA₄₊₇ plus 6-BA or the combined spray of GA₄₊₇/6-BA and P-Ca.

In 2010, fruit from trees treated with the combined spray of GA₄₊₇/6-BA and P-Ca had higher starch index values, but this was not observed in 2011; rather in this latter season, trees treated with 22 mg L⁻¹ GA₄₊₇ plus 6-BA had the higher starch index values (Table 2). Orthogonal contrasts indicated a significant linear ($P=0.0047$) and quadratic ($P=0.0232$) increase in starch index with increasing rates of GA₄₊₇ plus 6-BA. No treatment effect on the prevalence of stem-end cracking was observed in either year.

Significant treatment effects on the percent of the fruit surface with scarf skin were observed in both study years (Table 2). In 2010, P-Ca alone or in combination with GA₄₊₇ plus 6-BA reduced scarf skin by 10% compared to the untreated control ($P=0.0016$). There was also a linear reduction in scarf skin with increasing rates of GA₄₊₇ plus 6-BA ($P=0.0231$). In 2011, P-Ca alone reduced scarf skin by 7% compared to the untreated control ($P=0.0046$); however, this effect was negated when combined with GA₄₊₇ plus 6-BA. These data are consistent with other reports in the literature that found a reduction in scarf skin associated with GA₄₊₇ and P-Ca (McArtney et al. 2006).

Fruit Colour

In 2010, significant treatment differences in fruit blush colour (L^* , b , hue angle) were observed with smaller effects on fruit ground colour. Significant treatment differences in the L^* colour component were detected in the blush but not background colour (Table 3). A linear increase in L^* values was observed with increasing rates of GA₄₊₇ plus 6-BA ($P=0.004$). The same trend was also observed with the blush colour ' b ' and hue angle (h°) values, but no differences were observed in the ' a ' or chroma (C^*) values. Based on orthogonal contrasts, there were linear increases in blush colour ' b ' values ($P=0.013$) and hue angle values ($P=0.024$), both with increasing rates of GA₄₊₇ plus 6-BA. In 2011, there were significant treatment effects on blush L^* , b , and ground L^* , a , b , and hue angle values. Increasing rates of GA₄₊₇ plus 6-BA resulted in a quadratic increase in blush L and b values, and a linear increase in ground L^* , a , and hue angle values.

In 2010 these data indicate that GA₄₊₇ plus 6-BA treated fruit had a lighter and slightly more yellow blush colour with slightly greener background colour (McGuire 1992). In 2011, fruit were slightly lighter in colour and had more yellow in their blush colour. The ground colour was also lighter and slightly greener.

Fruit Shape and Size Distribution

In 2010, no significant treatment differences in fruit length, width, L:D ratio, or size distribution were observed in any of the twelve size categories (Table 4). There was a slight increase in fruit length with increasing rates of GA₄₊₇ plus 6-BA, resulting in numerically higher L:D ratio values, but treatment and/or fruit variation was such, and the magnitude of differences in the L:D ratio so small (< 1 mm), that these differences were not statistically different ($P>0.05$). The L:D values are consistent with those

observed in New Zealand (De Silva et al. 1997) but are considerable larger than those from a study in Argentina where L:D ratios were about ~ 0.80 (Dussi et al, 2005). Observations made in the orchard indicated that GA₄₊₇ plus 6-BA treated had more prominent calyx lobes at the basal/calyx end of the fruit, often referred to as “typiness” (Westwood 1993; Williams and Billingsley 1978). Unfortunately, in this trial specific measurements were not made to quantify these observations.

In 2011, while there was no significant treatment difference in fruit length, width, or L:D ratio, orthogonal contrasts indicated a significant linear increase in the L:D ratio with increasing rates of GA₄₊₇ plus 6-BA (Table 4). Fruit from trees which received 11 mg L⁻¹ GA₄₊₇ plus 6-BA had the higher L:D ratios than fruit from trees receiving either 5.5 or 21 mg L⁻¹ GA₄₊₇ plus 6-BA. In order to ascertain further potential differences in shape among GA₄₊₇ plus 6-BA treated fruit, fruit volumes were measured in 2011. Despite the large sample size per experimental unit (~ 100 fruits), no treatment differences in fruit volume or fruit density were detected.

Several proprietary products containing GA₄₊₇ and 6-BA, applied during flowering either alone or in combination, are reported in the literature to increase both the fruit L:D ratio and the prominence of calyx lobes producing more typey ‘Red Delicious’ (Buban et al, 1993; Jindal et al. 2004; Letham 1968; Stembridge and Morrell 1972; Westwood 1993; Williams and Billingsley 1978; Williams and Stahley 1969; Unrath 1974). In other studies on ‘Cox's Orange Pippin’ and ‘Alkmene’ apples in The Netherlands, no effect on fruit shape was observed (Jonkers and Borsboom 1981). Few, if any, reports in the scientific literature document the effect of GA₄₊₇ plus 6-BA on ‘Gala’.

The poor response of ‘Gala’ with respect to fruit typiness (L:D) ratios to GA₄₊₇

plus 6-BA in 2010 may be related to the cool weather immediately following application and the unusually warm growing season with ideal fruit development conditions. In a study by Westwood (1993) on 'Delicious', it was demonstrated that fruit typiness is related to the number of degree days above 5°C. 'Delicious' fruit grown in cooler regions, such as Wenatchee, WA had higher L:D ratios than 'Delicious' fruit grown in warmer regions such as Michigan and South Carolina. Various authors found that air temperatures during flowering and early fruit development are crucial in determining final fruit shape (Miller 1979; Shaw 1914; Westwood 1962). In several mountainous apple growing regions, air temperature is influenced by elevation. Veinbrants and Miller (1981) observed that fruit produced in north-eastern Victoria, Australia at relatively high elevations tend to have the characteristic elongated 'Delicious' shape because of low air temperature after blooming. However, many Delicious apples grown in coastal areas of southern Victoria at low elevations and high air temperatures after blooming tend to be flat rather than elongated and do not assume the characteristic 'Delicious' shape. Others argue that growing conditions have little or no effect, based on a study in a controlled environment that determined that air temperature and relative humidity had little or no influence on fruit shape (Tromp, 1990). Southern Ontario was warmer than usual in 2010 and as a result, fruit may have been less responsive to GA₄₊₇/6-BA.

The positive response in L:D ratios in 2011 to increasing concentrations of GA₄₊₇ and 6-BA indicate that this compound is effective in improving the length of 'Royal Gala' apples in some years. As with many plant bio-regulator studies, natural variation exists from year to year and the lack of any response in 2010 is not surprising giving the environmental conditions of that particular growing season. The data also further

indicate that in order to measure a response, sufficient numbers of fruit need to be evaluated in order to account for the natural shape variation that exists within and between trees. Observations on the tree at harvest did suggest that GA₄₊₇ plus 6-BA treated fruit were more elongated than the untreated controls, but assessment of sufficient numbers of fruit are required to demonstrate this effect statistically.

In both years of this study, very few treatment differences in fruit size distribution were detected (Table 4). This is most likely a result of the lack any significant treatment effect on fruit weight. In addition, fruit were hand-thinned to commercial levels (Robinson and Lopez 2010) and crop loads were relatively low in 2010 (average 3.4 fruit cm⁻² TCSA) and slightly higher than ideal in 2011 (average 8.0 fruit cm⁻² TCSA).

Shoot Length

Marked differences in shoot growth were observed among treatments in both years of this study (Figure 2). Maximal growth rate occurred between bloom and at approximately the end of June, 6-7 weeks after full bloom (WAFB) for the untreated trees. Shoot growth on trees treated with 21 mg L⁻¹ GA₄₊₇ and 6-BA was similar to the untreated control, with the exception that toward the end of May in both years (2-3 WAFB), the GA₄₊₇ and 6-BA treatments resulted in a slight but significant increase in shoot growth. This effect was transient and the difference from the control no longer observed by mid-June. Trees treated with P-Ca had significantly less growth (45% growth suppression) than the untreated trees or trees treated with GA₄₊₇ and 6-BA (P<0.001). In 2011, P-Ca reduced extension growth by approximately 21% by the end of the growing season. In 2010, growth was suppressed throughout the entire growing

season with the single PF application, while in 2011, shoot growth increased slowly but steadily to end of the growing season, albeit at a lower rate than the untreated controls. The addition of 21 mg L^{-1} GA₄₊₇ and 6-BA to P-Ca as a tank mix had an insignificant effect on overall shoot growth during the growing season. However, in 2011, the addition of GA₄₊₇ and 6-BA mitigated the effect of P-Ca, resulting in intermediate shoot growth between the untreated control and P-Ca alone, and similar to the 21 mg L^{-1} GA₄₊₇ and 6-BA alone treatment.

The antagonist effect of GA₄₊₇ on the efficacy of P-Ca regulating shoot growth has been observed previously on 'Golden Delicious', (McArtney et al, 2007) when a single application of P-Ca (138 to $167 \text{ mg} \cdot \text{L}^{-1}$) was tank-mixed with 15 - 20 mg GA₄₊₇ at PF followed by multiple applications of 10 - 20 mg L^{-1} GA₄₊₇ at 10-day intervals beginning at PF. The authors, however, observed that P-Ca, when applied alone or in combination with GA₄₊₇, reduced russet rather than negated the effect of GA₄₊₇ on fruit russet (McArtney et al, 2006) and scarf skin (McArtney et al, 2007). The inhibition by P-Ca on shoot growth is postulated to be a result of competition with the natural co-substrate, 2-oxoglutarate, which is similar in structure to P-Ca (Costa et al, 2006; Rademacher, 2000; Rademacher, 2006). This process occurs in the later stages of the gibberellin biosynthesis pathway where P-Ca inhibits the metabolism of GA₂₀-3 β -hydroxylase (Brown et al, 1987). P-Ca also inhibits the 2 β -hydroxylase enzymes responsible for inactivation of endogenously active GAs such as GA₁ and GA₄ (Rademacher and Kober, 2003). Such inactivation by P-Ca may result in elevated endogenous levels of GA₄ as a result of reduced conversion to inactive forms. Consequently, less growth-

promoting gibberellins are formed and vegetative shoot growth of treated plants is reduced.

Further investigation is warranted to determine whether the inhibitory effect of GA₄₊₇ plus 6-BA on P-Ca efficacy is present when GA₄₊₇ and 6-BA are applied separately. It is conceivable that the exogenous GA₄₊₇, 6-BA, or other ingredients in the proprietary Promalin™ product, influences the activity of the P-Ca molecule prior to absorption, directly affecting uptake into the plant vis-a-vis the surfactants in the tank mixture, or that metabolism of GA and P-Ca was affected at the cellular level. The effect of 6-BA when tank-mixed with P-Ca efficacy is unknown. In a study on 'Lobo' apple in Poland, 6-BA had no effect on the efficacy of P-Ca when applied during fruit set 4-7 days after P-Ca (Basak and Krzewinska, 2006). With respect to orchard management, when P-Ca is used in conjunction with PF sprays of GA, an initially higher rate of P-Ca may be required to compensate for the GA-mediated reduction in growth control. The interaction of single sprays of GA₄₊₇ and 6-BA sprays on subsequent repeat applications of P-Ca, typically applied at 14 d intervals, is also unknown.

Furthermore, a more definitive response of GA₄₊₇ plus 6-BA on the L:D ratio and fruit typiness would help ascertain with greater certainty any negative or positive effects of P-Ca on these parameters.

CONCLUSION

A mixture of GA₄₊₇ and the cytokinin 6-benzyladenine were effective in one out of two two years in improving the typiness of 'Gala' apples. Increasing rates of GA₄₊₇ plus 6-BA between 5 and 21 mg L⁻¹ decreased soluble solids and fruit firmness in one year of two

years, indicating early seasons sprays affect fruit quality at harvest. P-Ca alone reduced scarf skin by 7-10%, however, this effect was negated when combined with GA₄₊₇ plus 6-BA in one of the two years. Trees treated with P-Ca had 21-45% less growth than the untreated trees or trees treated with GA₄₊₇ and 6-BA, depending on year. In one of two years, the addition of GA₄₊₇ and 6-BA tank-mixed with P-Ca reduced the efficacy of P-Ca on shoot growth. The hypothesis that GA₄₊₇/6-BA and PC interact to affect the efficacy of either or both compounds was confirmed. Apple producers should consider using higher rates of P-Ca when tanking mixing with Promalin® and similar proprietary products, to obtain comparable growth control when using P-Ca alone.

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Figure 1a. Daily minimum and maximum air temperature and precipitation from April to October, 2010 at the University of Guelph, Simcoe Research Station, Simcoe, Ontario.

Figure 1a. Air temperature (line) and rainfall (bars) recorded every 15 minutes from 1-May and 14-May, 2010 at the University of Guelph, Simcoe Research Station, Simcoe, Ontario.

Figure 1c. Daily minimum and maximum air temperature and precipitation from April to October, 2011 at the University of Guelph, Simcoe Research Station, Simcoe, Ontario.

Figure 2. Extension shoot growth of 'Gala' apple trees in 2010 (A) and 2011 (B) as affected by different GA₄₊₇/6-BA and prohexadione-calcium (P-Ca) treatments. Legend: untreated control (●); 21 mg L⁻¹ each of GA₄₊₇ and 6-BA (▽); 123 mg L⁻¹ P-Ca(■), and; combination of treatments 3 and 4 (◇). Error bars represent the standard error of the means. Arrows indicate the application dates (i.e., May 5, 2010 and May 24, 2011).

Table 1. Tree vigor, mean fruit weight, number of fruit per tree, crop load, and pre-harvest drop of 'Gala' apples as affected by different concentrations of GA₄₊₇ plus 6-BA and prohexadione-calcium.

Treatment	Trunk cross-sectional area (cm ²)	Return bloom rating (0-4)	Mean fruit weight (g)	Total number of fruit/tree	Total fruit weight/tree (kg)	Crop load (no. frt cm ⁻² TCA)	Pre-harvest fruit drop (%)
2010							
Untreated control	42.2	-	200.9	128.7	25.8	3.4	14.9
GA ₄₊₇ + 6-BA 5.5 mg L ⁻¹	44.8	-	192.0	146.5	28.1	3.6	13.4
GA ₄₊₇ + 6-BA 11 mg L ⁻¹	46.6	-	194.6	161.6	31.4	3.7	20.5
GA ₄₊₇ + 6-BA 21 mg L ⁻¹	54.6	-	191.1	157.9	30.1	3.0	18.7
Prohexadione-calcium (PC)	42.2	-	202.6	144.2	29.2	4.2	15.3
PC, GA ₄₊₇ + 6-BA 21 mg L ⁻¹	49.6	-	195.0	155.7	29.8	3.3	13.8
<i>P</i> value	0.3421	-	0.3939	0.4641	0.5973	0.6372	0.1027
Contrasts (<i>P</i> value)							
Rate of GA ₄₊₇ + 6-BA - Linear	0.1220	-	0.2011	0.0453	0.0706	0.8261	0.0337
Rate of GA ₄₊₇ + 6-BA - Quadratic	0.8868	-	0.3437	0.9096	0.8959	0.7513	0.0969
Control vs PC	1.0000	-	0.7926	0.3818	0.2952	0.2750	0.8985
PC +/- GA ₄₊₇ + 6-BA	0.2463	-	0.2420	0.5157	0.8355	0.2164	0.6055
2011							
Untreated control	53.8	4.3	140.4	380.5	52.9	7.5	6.1
GA ₄₊₇ + 6-BA 5.5 mg L ⁻¹	46.0	4.2	136.7	342.4	46.7	8.7	5.6
GA ₄₊₇ + 6-BA 11 mg L ⁻¹	59.3	4.1	140.7	403.1	56.7	7.1	4.8
GA ₄₊₇ + 6-BA 21 mg L ⁻¹	49.6	4.3	132.3	416.1	54.6	8.8	5.5
Prohexadione-calcium (PC)	47.2	4.2	146.9	385.6	56.3	8.5	5.1
PC, GA ₄₊₇ + 6-BA 21 mg L ⁻¹	47.7	4.3	138.6	390.1	53.7	8.8	5.6
<i>P</i> value	0.3698	0.8120	0.0986	0.3612	0.2632	0.5256	0.8965
Contrasts (<i>P</i> value)							
Rate of GA ₄₊₇ + 6-BA - Linear	0.6895	0.4871	0.4271	0.1937	0.2874	0.8384	0.3212

Rate of GA ₄₊₇ + 6-BA -							
Quadratic	0.1113	0.7002	0.5140	0.0726	0.0392	0.2382	0.9397
Control vs PC	0.3356	0.4733	0.1891	0.8796	0.4549	0.4096	0.3813
PC +/- GA ₄₊₇ + 6-BA	0.9421	0.6989	0.0954	0.8937	0.5676	0.7516	0.6606

For Review Only

Table 2. Fruit quality parameters of 'Gala' apples as affected by different concentrations of GA₄₊₇ plus 6-BA and prohexadione-calcium.

Treatment	Soluble Solids (%)	Fruit firmness (lb)	Russet Rating (0-3)	Percent surface red blush (%)	Starch Index (1-8)	Stem-end cracking (%)	Scarf Skin (% of surface)
2010							
Untreated Control	13.7	7.4 b ^z	1.9	81.2	6.3 b	18.32	32.0 a
GA ₄₊₇ + 6-BA 5.5 mg L ⁻¹	13.3	7.5 ab	1.9	80.2	6.4 b	8.34	32.2 a
GA ₄₊₇ + 6-BA 11 mg L ⁻¹	13.2	7.3 b	1.8	77.3	6.6 ab	18.34	25.9 ab
GA ₄₊₇ + 6-BA 21 mg L ⁻¹	13.3	7.7 a	2.0	81.8	6.3 b	8.33	26.5 ab
Prohexadione-calcium (PC)	13.7	7.4 b	1.8	76.4	6.4 b	10.00	22.8 b
PC, GA ₄₊₇ + 6-BA 21 mg L ⁻¹	13.2	7.4 b	1.6	80.2	6.9 a	11.66	20.3 b
<i>P</i> value	0.2283	0.0030	0.6470	0.0940	0.0043	0.4543	0.0016
Contrasts (<i>P</i> value)							
Rate of GA ₄₊₇ + 6-BA - Linear	0.0568	0.6760	0.6853	0.2902	0.3052	0.6710	0.0231
Rate of GA ₄₊₇ + 6-BA - Quadratic	0.5983	0.2939	0.9374	0.8126	0.9057	0.1209	0.2398
Control vs PC	0.9379	0.4481	0.7312	0.0255	0.7907	0.2130	0.0075
PC +/- GA ₄₊₇ + 6-BA	0.0860	0.7826	0.3907	0.0773	0.0016	0.7996	0.4485
2011							
Untreated Control	11.5	8.1 a	1.3	73.4 ab	5.1 c	0.00	13.7 a
GA ₄₊₇ + 6-BA 5.5 mg L ⁻¹	12.0	7.9 b	1.4	78.0 a	5.8 ab	0.05	16.1 a
GA ₄₊₇ + 6-BA 11 mg L ⁻¹	11.5	8.1 a	1.3	73.5 ab	5.4 bc	0.05	17.8 a
GA ₄₊₇ + 6-BA 21 mg L ⁻¹	11.6	7.9 b	1.3	71.3 b	6.2 a	0.05	13.1 a
Prohexadione-calcium (PC)	11.4	8.0 ab	1.0	74.6 ab	5.3 c	0.00	6.7 b
PC, GA ₄₊₇ + 6-BA 21 mg L ⁻¹	10.8	8.0 ab	1.3	78.0 a	5.5 bc	0.02	14.8 a
<i>P</i> value	0.7227	0.0431	0.3712	0.0384	0.0001	0.4226	0.0046
Contrasts (<i>P</i> value)							
Rate of GA ₄₊₇ + 6-BA - Linear	0.9485	0.3075	0.9699	0.3859	0.0047	0.1395	0.5588
Rate of GA ₄₊₇ + 6-BA - Quadratic	0.4113	0.0045	0.2939	0.0199	0.0232	0.4061	0.4286
Control vs PC	0.8780	0.0846	0.2086	0.6390	0.5010	1.0000	0.0158

PC +/- GA ₄₊₇ + 6-BA	0.4461	0.4803	0.1270	0.1701	0.2818	0.6375	0.0005
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^z average values with the same letter within a given column are not significantly different according to Duncan's multiple range test at *P*=0.05.

For Review Only

Table 3. Fruit skin blush and ground colour of 'Gala' apples as affected by different concentrations of GA₄₊₇ plus 6-BA and prohexadione-calcium.

		Blush Colour						
Treatment		L*	a	b	Chroma	Hue Angle		
2010								
Untreated Control	44.8	b ^z	38.8	20.1	a	43.8	27.4	bc
GA ₄₊₇ + 6-BA 5.5 mg L ⁻¹	44.8	b	39.1	8	b	43.9	1	c
GA ₄₊₇ + 6-BA 11 mg L ⁻¹	46.7	a	38.7	21.1	a	44.1	6	c
GA ₄₊₇ + 6-BA 21 mg L ⁻¹	47.2	a	37.1	21.1	a	43.3	2	a
Prohexadione-calcium (PC)	46.4	b	37.8	21.2	a	43.7	6	ab
PC, GA ₄₊₇ + 6-BA 21 mg L ⁻¹	45.3	a	38.3	20.5	a	43.5	2	ab
	3	b		5	b			c
<i>P</i> value		0.0243	0.1210	0.0313	0.5814	0.0396		
Contrasts (<i>P</i> value)								
Rate of GA ₄₊₇ + 6-BA - Linear	0.0032	0.1471	0.0133	0.7587	0.0215			
Rate of GA ₄₊₇ + 6-BA - Quadratic	0.1651	0.4042	0.0864	0.8538	0.2275			
Control vs PC	0.0777	0.2009	0.0327	0.8473	0.0498			
PC +/- GA ₄₊₇ + 6-BA	0.2210	0.5339	0.1509	0.6680	0.2270			
2011								
Untreated Control	46.1	a	37.2	19.5	a	42.2	27.8	
GA ₄₊₇ + 6-BA 5.5 mg L ⁻¹	44.9	b	37.6	18.7	b	42.1	26.6	
GA ₄₊₇ + 6-BA 11 mg L ⁻¹	48.0	a	37.2	20.5	a	42.8	29.3	
GA ₄₊₇ + 6-BA 21 mg L ⁻¹	47.1	a	36.9	19.5	a	41.9	28.3	
Prohexadione-calcium (PC)	47.0	a	36.6	19.8	a	41.9	28.8	
PC, GA ₄₊₇ + 6-BA 21 mg L ⁻¹	46.2	a	36.5	19.4	a	41.7	28.3	
	2	b		4	b			
<i>P</i> value		0.0266	0.8491	0.0191	0.5802	0.2794		
Contrasts (<i>P</i> value)								
Rate of GA ₄₊₇ + 6-BA - Linear	0.0482	0.8717	0.1092	0.5832	0.2617			
Rate of GA ₄₊₇ + 6-BA - Quadratic	0.0090	0.5459	0.0059	0.7092	0.0606			
Control vs PC	0.4256	0.6091	0.5305	0.8124	0.4766			
PC +/- GA ₄₊₇ + 6-BA	0.4068	0.9089	0.4353	0.6600	0.7029			
Ground Colour								
Treatment		L*	a	b	Chroma	Hue Angle		
2010								

Untreated Control	69.3	4. 9 a	33.4	34.9	81. 2 b
GA ₄₊₇ + 6-BA 5.5 mg L ⁻¹	70.1	4. 8 a	32.4	34.2	81. 4 b
GA ₄₊₇ + 6-BA 11 mg L ⁻¹	70.8	3. 2 ab	33.9	35.4	83. 8 ab
GA ₄₊₇ + 6-BA 21 mg L ⁻¹	72.2	1. 1 b	33.7	34.7	87. 6 a
Prohexadione-calcium (PC)	72.5	0. 4 b	34.7	35.3	88. 9 a
PC, GA ₄₊₇ + 6-BA 21 mg L ⁻¹	70.9	1. 3 b	34.3	34.9	87. 5 a
<i>P</i> value	0.1265	0.0036	0.0731	0.5204	0.0026
Contrasts (<i>P</i> value)					
Rate of GA ₄₊₇ + 6-BA - Linear	0.0524	0.0230	0.3877	0.5920	0.0252
Rate of GA ₄₊₇ + 6-BA - Quadratic	0.8557	0.3812	0.0597	0.1232	0.4256
Control vs PC	0.0160	0.0026	0.1043	0.5378	0.0020
PC +/- GA ₄₊₇ + 6-BA	0.2311	0.5775	0.5715	0.5212	0.5873
2011					
Untreated Control	72. 9 b	4. 3 ab	32. 1 b	34.4	81. 1 bc
GA ₄₊₇ + 6-BA 5.5 mg L ⁻¹	72. 9 b	5. 4 a	30. 9 b	33.5	79. 6 c
GA ₄₊₇ + 6-BA 11 mg L ⁻¹	75. 5 a	1. 2 bc	33. 4 a	35.0	86. 8 ab
GA ₄₊₇ + 6-BA 21 mg L ⁻¹	75. 4 a	0. 8 bc	32. 9 a	34.2	87. 7 ab
Prohexadione-calcium (PC)	75. 0 b	0. 1 c	33. 6 a	34.8	88. 8 a
PC, GA ₄₊₇ + 6-BA 21 mg L ⁻¹	73. 4 b	3. 1 c	32. 2 b	33.8	83. 6 c
<i>P</i> value	0.0156	0.0175	0.0026	0.1055	0.0153
Contrasts (<i>P</i> value)					
Rate of GA ₄₊₇ + 6-BA - Linear	0.0025	0.0134	0.0181	0.2225	0.0108
Rate of GA ₄₊₇ + 6-BA - Quadratic	0.1869	0.1031	0.0117	0.0763	0.1176
Control vs PC	0.0408	0.0190	0.0245	0.2428	0.0154
PC +/- GA ₄₊₇ + 6-BA	0.1272	0.1034	0.0531	0.0955	0.1007

^z average values with the same letter within a given column are not significantly different according to Duncan's multiple range test at *P*=0.05.

Table 4. Fruit length, width, length:diameter ratio, and grade distribution of 'Gala' apples as affected by different concentrations of GA₄₊₇ plus 6-BA and prohexadione-calcium.

Treatment	2010																	
	Fruit weight (g)	Fruit Length (mm)	Fruit width (mm)	L:D ratio	Volume (cm ³)	Density (g/cm ³)	Fruit distribution (% by number)											
							Juice (<198)	2 1/4 " (198)	2 3/8 " (175)	2 1/2 " (163)	2 5/8 " (150)	2 3/4 " (138)	2 7/8 " (125)	3 " (113)	3 1/8" (100)	3 1/4 " (88)	3 3/8" (72)	
Untreated Control	202.3	74.3	78.1	0.951	-	-	0.3	0.5	0.3	3.6	5.4	11.0	16.8	21.5	20.0	10.6	6.5	
GA ₄₊₇ + 6-BA 5.5 mg L ⁻¹	195.8	74.2	77.5	0.958	-	-	0.3	0.3	0.6	3.6	7.1	15.5	18.5	20.8	20.4	7.1	2.7	
GA ₄₊₇ + 6-BA 11 mg L ⁻¹	205.4	75.0	78.1	0.959	-	-	0.7	0.2	1.2	2.0	4.8	8.3	15.9	19.7	28.6	8.6	6.4	
GA ₄₊₇ + 6-BA 21 mg L ⁻¹	201.2	75.0	77.8	0.963	-	-	0.0	0.2	0.5	2.2	5.9	12.5	17.8	22.4	22.8	8.3	4.4	
Prohexadione-calcium (PC)	208.8	75.1	77.9	0.965	-	-	0.2	0.2	0.7	2.0	4.7	11.1	12.8	19.1	22.4	13.6	7.6	
PC, GA ₄₊₇ + 6-BA 21 mg L ⁻¹	195.7	75.2	77.9	0.966	-	-	1.3	0.3	1.0	3.8	6.9	11.9	17.9	19.9	22.9	9.7	2.7	
<i>P</i> value	0.1470	0.6753	0.8499	0.7221	-	-	0.0941	0.8456	0.6682	0.8164	0.6400	0.1565	0.3096	0.7766	0.2583	0.0990	0.0555	
Contrasts (<i>P</i> value)																		
Rate of GA ₄₊₇ + 6-BA - Linear	0.6323	0.2772	0.9223	0.2586	-	-	0.9730	0.1981	0.2728	0.3101	0.7995	0.4779	0.8998	0.8385	0.0544	0.3712	0.764	
Rate of GA ₄₊₇ + 6-BA - Quadratic	0.1166	0.4657	0.1863	0.8595	-	-	0.8741	0.9431	0.9645	0.6304	0.2154	0.0179	0.4105	0.9342	0.3256	0.2040	0.034	
Control vs PC	0.2540	0.3268	0.6005	0.1931	-	-	0.7263	0.2748	0.5356	0.4002	0.6761	0.9906	0.1359	0.3369	0.5216	0.2047	0.603	
PC +/- GA ₄₊₇ + 6-BA	0.0235	0.8560	0.8993	0.9295	-	-	0.0182	0.6969	0.5606	0.3410	0.2215	0.7368	0.0591	0.7572	0.8919	0.0942	0.015	
Treatment	2011																	
	Fruit weight (g)	Fruit Length (mm)	Fruit width (mm)	L:D ratio	Volume (cm ³)	Density (g/cm ³)	Fruit distribution (% by number)											
							Juice (<198)	2 1/4 " (198)	2 3/8 " (175)	2 1/2 " (163)	2 5/8 " (150)	2 3/4 " (138)	2 7/8 " (125)	3 " (113)	3 1/8" (100)	3 1/4 " (88)	3 3/8" (72)	
Untreated Control	147.3	64.8	67.7	0.958	195.4	0.853	0.3	2.2	9.3	29.9	25.9	16.8	9.4	3.2	2.0	0.5	0.0	
GA ₄₊₇ + 6-BA 5.5 mg L ⁻¹	147.7	66.0	68.3	0.967	194.2	0.860	0.6	2.9	8.1	33.9	27.7	15.0	6.7	2.5	0.8	0.4	0.0	
GA ₄₊₇ + 6-BA 11 mg L ⁻¹	153.7	67.1	68.7	0.978	200.0	0.854	0.0	0.6	5.5	26.7	30.3	21.6	9.2	2.5	1.5	0.1	0.0	
GA ₄₊₇ + 6-BA 21 mg L ⁻¹	141.8	64.9	67.0	0.967	194.9	0.854	0.6	3.4	12.9	33.7	24.3	17.7	6.7	1.1	0.4	0.2	0.1	
Prohexadione-calcium (PC)	152.2	66.8	69.1	0.968	204.5	0.852	0.1	2.2	6.0	26.5	26.0	22.1	9.8	2.9	1.3	0.3	0.2	
PC, GA ₄₊₇ + 6-BA 21 mg L ⁻¹	147.6	66.7	68.0	0.981	197.0	0.857	0.5	1.8	10.2	32.2	24.9	19.6	8.2	1.4	0.3	0.4	0.3	
<i>P</i> value	0.3567	0.0584	0.2362	0.0301	0.332	0.539	0.4887	0.7378	0.4921	0.6301	0.5375	0.3914	0.7898	0.5080	0.0251	0.7438	0.137	
Contrasts (<i>P</i> value)																		
Rate of GA ₄₊₇ + 6-BA - Linear	0.8571	0.1674	0.8565	0.0185	0.556	0.964	0.8328	0.7882	0.9695	0.9056	0.6317	0.2864	0.6666	0.2157	0.0651	0.1358	0.658	
Rate of GA ₄₊₇ + 6-BA - Quadratic	0.8109	0.6599	0.6139	0.9859	0.517	0.095	0.2601	0.4714	0.9270	0.3314	0.8838	0.2558	0.3414	0.8887	0.0964	0.7104	0.901	
Control vs PC	0.3805	0.0376	0.1082	0.1681	0.080	0.814	0.6066	1.0000	0.4280	0.5503	0.9767	0.1725	0.8869	0.8139	0.2167	0.4828	0.143	
PC +/- GA ₄₊₇ + 6-BA	0.4117	0.8719	0.2089	0.0746	0.178	0.324	0.3050	0.8287	0.3141	0.3182	0.7478	0.5169	0.5702	0.2422	0.0800	0.7252	0.461	

For Review Only