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Improving 'Bing' sweet cherry fruit quality with plant growth regulators

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ABSTRACT

Final fruit diameter is the prime determinant of sweet cherry fruit value. Previous research has shown that mesocarp cell size accounts predominantly for variability in final fruit size, within a genotype. Our research program evaluated the potential to improve sweet cherry fruit size/weight with growth regulators to affect cell division and/or cell expansion stages. In the current study we screened 8 plant growth regulators (PGRs), including cytokinins, gibberellins, and auxins, and their combinations for their ability to increase 'Bing' fruit weight. Each PGR was mixed in lanolin paste and applied to fruit pedicels at 9 or 30 days after full bloom (DAFB), to coincide with estimated peak in cell division and cell expansion activity, respectively. Several cytokinins applied 30 DAFB improved fruit weight significantly (ca. +15%) with N-(2-Chloro-4-pyridyl)-N′-phenylurea (CPPU) and 6-(3-hydroxybenzylamino) purine (mt-Topolin) at 100 mg l^{-1} being the most effective. Gibberellins, applied alone, improved fruit size and delayed fruit maturation and exocarp coloration. GA_3 at 200 mg l^{-1} applied at 9 DAFB was the most effective and improved final fruit weight by 15%. Fifty-six percent of the fruit from this treatment were ≥9 g compared to 15% of similar weight fruit from untreated limbs. Both GA_3 and $GA_{4/7}$ treatments applied 9 DAFB increased fruit radial expansion. 4-Chlorophenoxyacetic acid, a synthetic auxin, also stimulated higher fruit growth rates at stage I and stage II, and fruit color development, but did not improve final fruit size.

1. Introduction

The recent increase in cherry (*Prunus avium* L.) production worldwide has placed new importance on fruit quality, and maintaining quality throughout the supply chain (World Sweet Cherry Review, 2009). The 2009 sweet cherry crop in the Pacific Northwest of the USA was record-breaking and many orchards were over-set with an abundance of under-sized fruit. This recent experience underscores the importance of balancing crop load and increasing fruit size and quality. For sweet cherry, fruit size remains the most important fruit quality attribute, and developing pragmatic strategies for improving fruit size is of great interest. Previous research has suggested that rootstock and scion genetics, crop load, and environmental factors each affect final fruit size and quality (Whiting and Lang, 2004; Whiting and Ophardt, 2005; Lenahan et al., 2006).

Mature cherry fruit are composed of a thin protective exocarp, a fleshy mesocarp, and an inedible stony endocarp (pit) surrounding the seed (Esau, 1977). Fruit growth of sweet cherry follows a double-sigmoid growth curve, consisting of three distinct growth stages: stage I, mesocarp growth consists of both cell division and cell enlargement; stage II, a lag period of fruit growth coinciding with endocarp hardening and embryo development; and stage III, a second period of exponential fruit growth with rapid cell expansion (Coombe, 1976; Tukey and Young, 1939). The increase in fruit size in many fruit species result from cell division, cell expansion or a coordinated series of cell division and expansion (Scorza et al., 1991; Yamaguchi et al., 2004; Zhang et al., 2006). Our previous research has also suggested that mesocarp cell size accounts for most variability in fruit size within a genotype and was significantly influenced by the environment, indicating that cultural practices that maximize mesocarp cell size should be used to achieve a cultivar's fruit size potential (Olmstead et al., 2007).

Most of research on plant growth regulators on cherry fruit quality focused on preharvest application of gibberellins (GA_3) made during the stages II–III transition to increase fruit size and delay maturation (Proebsting et al., 1973; Facteau et al., 1985; Kappel and MacDonald, 2002, 2007; Clayton et al., 2006; Lenahan et al., 2006). Our unpublished data showed that foliar applications of GA_3 in combination with prohexadione calcium, at the onset of stage II of fruit development (i.e., ca. 3 weeks prior to industry standard timing), show potential to affect canopy source-sink relations and improve quality and shelf life of 'Bing' sweet cherries (Zhang and Whiting, unpublished). Further, a recent study in 'Bing' cherry showed that synthetic auxins applied at the beginning of pit-hardening caused a significant improvement in fruit size and total yield (Stern et al., 2007). These previous reports verify the potential for improving fruit size and quality of sweet cherry with plant growth regulators. However, no studies to date have evaluated a wide range of plant growth regulators applied at key stages of fruit development. The objective of the current study was to screen can-

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Table 1
Effect of PGRs application during rapid cell division on fruit weight (g), firmness (mg/mm^2), TSS (Brix) and color rating (CTIFL) of sweet cherry 'Bing'.

Treatment	Fruit weight (g)	Firmness (mg/mm^2)	TSS (Brix)	Color (CTIFL)[d]
Control	7.9g[a]	223k	22.8ab	4.8
CPPU 50[b]	8.6bc	283a	23.1a	4.3
CPPU 100	9.1a	250defgh	22.2abc	3.7
Topolin 50	8.0fg	257bcdef	21.7abcde	3.8
Topolin 100	9.2a	237hijk	20.3efgh	3.5
TDZ 50	8.9ab	269ab	21.9abcde	3.9
TDZ 100	8.8bc	253cdefg	21.4bcdef	4.2
BA 50	8.6bc	264bcd	22.6ab	4.3
CPA 100	8.1efg	242fghij	22.3abc	5.4
GA_1 200	8.8ab	246efghi	21.5abcdef	4.8
GA_1 500	8.7bc	255bcdef	21.9abcde	4.9
GA_3 200	8.8ab	249efgh	20.5defg	4.4
GA_3 500	8.6bc	238ghijk	22.0abcd	4.1
$GA_{4/7}$ 200	8.2def	258bcde	20.8cdefg	4.2
$GA_{4/7}$ 500	8.1efg	224k	22.4ab	4.0
$GA_3 + GA_{4/7}$[c]	8.6bc	228jk	20.0fgh	3.8
CPPU + GA_1	8.7bc	247efghi	21.5abcdef	4.8
CPPU + GA_3	8.6bc	255bcdef	22.3abc	3.0
CPPU + $GA_{4/7}$	8.5cde	267bc	22.2abc	3.3
CPPU + GA_3 + $GA_{4/7}$	8.6bc	233ijk	21.7abcde	4.2
CPPU + GA_3 + CPA	8.5bcde	223k	18.8h	3.1

[a] Means followed by the same letters are not significantly different ($p = 0.05$) by Duncan's new multiple range test.
[b] The chemical abbreviations followed by its concentration at mg l^{-1}.
[c] The concentration of CPPU, GAs, CPA in the combination was 50, 200, and 100 mg l^{-1}, respectively.
[d] Color rating: the higher number indicates dark color.

didate plant growth regulators, of several classes, for their potential to improve fruit growth during cell division (i.e., stage I) and/or cell expansion (i.e., stage III) in sweet cherry.

2. Materials and methods

All research was conducted at Washington State University's Roza farm, Prosser, WA, USA (N 46.2°, W 119.7°). Eleven-year-old 'Bing'/'Gisela® 1' sweet cherry trees trained to a central leader architecture were utilized.

2.1. Chemicals and abbreviations

In this study, we compared growth regulators from three families, including cytokinins, gibberellins, and auxins. Four synthetic cytokinins were included: N6-Benzyladenine (BA), N-(2-Chloro-4-pyridyl)-N′-Phenylurea (CPPU), 6-(3-hydroxybenzylamino) purine (Topolin), and N-phenyl-N′-(1,2,3-thiadiazol-5-yl) urea (TDZ). The three gibberellic acid isomers included were gibberellin A1 (GA_1), gibberellin A3 (GA_3), and the mixture of gibberellin A4 and A7 ($GA_{4/7}$). Lastly, we included the synthetic auxin, 4-chlorophenoxyacetic acid (CPA). All plant growth regulators used in this study were purchased from OlChemIm Ltd., Czech Republic.

2.2. Plant growth regulators application

The experiments included 21 treatments at cell division stage and 14 treatments at cell expansion stage including the lanolin-treated control. The PGRs listed above were applied at various rates alone (50, 100 ppm for cytokinins, but BA only at 50 ppm; 200, 500 ppm for GAs; 100 ppm for CPA) or in various combinations of CPPU, GAs and CPA (Table 1). Topolin, TDZ and BA were not included in the applications made at the cell expansion stage, and CPPU was applied only at 100 ppm. For treatments with PGR combinations, we used CPPU, GAs, CPA in the concentrations of 50, 200, and 100 mg l^{-1}, respectively. PGR treatments were made to all cherries ($n = 80$–190) within sections of two-year-old fruiting wood on each of three replicate limbs from 'Bing'/'Gisela® 1' trees (1 limb/tree) at the WSU-Prosser Roza orchards. Treatments were made by applying the growth regulators premixed in lanolin paste (10–15 mg for each fruit) directly to the middle 1/3 section of the pedicels. The treatments were applied at either 9 or 30 days after full bloom to coincide roughly with estimated peak in cell division and cell expansion activity, respectively. Twenty fruit per treatment were selected randomly for fruit length and width measurement at weekly interval. The daily fruit growth rate was calculated based on fruit length and fruit width. All fruit were harvested on the same day (June 27, 2008) and analyzed individually for quality attributes within 48 h of harvest.

2.3. Fruit quality analyses

Each fruit was weighed individually to facilitate assessment of fruit size distribution. The fruit shape index was calculated from the ratio of fruit width and fruit length form 20 randomly selected fruit. Each fruit was also categorized by exocarp color manually according to the sweet cherry color plates (1–7 scale) developed by CTIFL (Centre technique interprofessionnel des fruit et legumes, France). Fruit number in each category was counted and calculated for color distribution and color rating. Subsequently, all fruit were subjected to concomitant firmness testing and equatorial diameter measurement using a calibrated FirmTech II (BioWorks, Inc., KS, USA). Then, 25 fruit were randomly selected for five 5-fruit replicates for determination of soluble solids content. Fruit soluble solids were measured using a digital refractometer (Atago, Japan). Approximately 0.5 ml of juice was dropped directly onto the surface of the refractometer and the measurement immediately taken.

2.4. Statistical analyses

All trials were established as randomized complete-block designs. All data were subjected to analysis of variance using the general linear models (GLM) program of the SAS statistical analysis package (SAS Institute, Cary, North Carolina). Duncan's new multiple range test and were used to compare treatments when ANOVA showed significant differences between means.