Efficacy of ACC (1-aminocyclopropane-1-carboxylic acid) as a Chemical Thinner Alone or Combined with Mechanical Thinning for Japanese Plums (Prunus salicina)

Karen Inge Theron\textsuperscript{1}
Department of Horticultural Science, Stellenbosch University, Private Bag XI, Matieland 7602, South Africa

Human Steenkamp
Stellenbosch University, Stellenbosch 7599, South Africa

Willem Jacobus Steyn
Department of Horticultural Science, University of Stellenbosch, Victoria Street, Stellenbosch 7600, South Africa

Additional index words. 6-benzyladenine (6-BA), thinning, yield, fruit quality

Abstract. Thinning is a labor-intensive and expensive, but important practice in Japanese plum production requiring new thinning strategies. The purpose of this study was to evaluate a new chemical thinner 1-aminocyclopropane-1-carboxylic acid (ACC) on ‘Laetitia’, ‘Fortune’, and ‘African Rose™’. ACC was also combined with 6-benzyl adenine (6-BA) and in one season on ‘African Rose™’ with mechanical thinning using the Darwin 300\textsuperscript{TM} or hand thinning during bloom. All the foliar applications were made when the average fruitlet diameter was 7–10 mm using a spray volume of 1000 L ha\textsuperscript{-1} under slow drying conditions. Significant thinning effects were found in all the trials conducted over the two seasons. ACC consistently reduced the hand-thinning requirement at commercial hand thinning in both seasons in ‘African Rose™’. In the second season there was a linear decrease in yield and an increase in fruit size as the ACC rate increased from the low to medium rate before flattening off. The combination treatment of ACC and the Darwin 300\textsuperscript{TM} used in the ‘African Rose™’ trial thinned more aggressively, improved fruit size and shifted harvest earlier. The yield however was not lower than that of the control treatment. 6-BA was included in all trials to prevent ACC-induced leaf drop, and generally did not thin fruitlets, except in the case of ‘Laetitia’ where the combination with ACC resulted in stronger thinning. Cultivars differed in their sensitivity to ACC and the rate for each cultivar should be determined separately. The recommended ACC rate for ‘African Rose™’ would be 600 µL·L\textsuperscript{-1} and for ‘Laetitia’ 400 µL·L\textsuperscript{-1}. For ‘Fortune’ a rate recommendation is not possible at this stage, thus further trials should be conducted. No broken stones were observed in fruit in any trial. Also, no leaf drop/phytotoxicity was recorded in any trial when ACC was applied during cool, slow-drying conditions.

Annual cropping of fruit trees is very important and to achieve this, flower or fruit thinning is practiced. By reducing the number of fruit on the tree, the remaining fruit will develop to the optimal size of higher quality and return bloom the next season will be adequate for a good crop load (Njoroge and Reighard, 2008). Thinning can be done at various times, i.e., prebloom, full bloom, and postbloom, and the cheapest and earliest method of thinning is pruning (Njoroge and Reighard, 2008). However, even when stone fruit trees are properly pruned, they still often set too many fruit (DeJong and Grossman, 1994). The severity of thinning as well as the timing is closely linked to the reproductive and vegetative performance of the tree (Costa and Vizzotto, 2000). Appropriate thinning must therefore be done annually, to achieve the advantages it has on flower number, fruit size, fruit quality, fruit-to-shoot ratio, and in preventing alternate bearing (Costa et al., 1983; Seehuber et al., 2011).

Chemical thinning plums would reduce hand thinning substantially, but currently, chemical thinners available for stone fruit thinning are limited (Seehuber et al., 2011). One chemical thinning approach for plums is to use gibberellins, e.g., gibberellic acid (GA\textsubscript{3}), but results are often inconsistent. GA\textsubscript{3} applied during flower induction will reduce flowering the next season and indirectly reduce the number of fruit, which will lead to a reduction in hand-thinning costs (González-Rossia et al., 2006). Therefore, to be effective, GA\textsubscript{3} must be applied when flower-bud differentiation can be affected (Costa and Vizzotto, 2000). The main reason why GA\textsubscript{3} sprays are not used as a chemical thinner is “thinning” is performed long before bloom and climatic conditions, i.e., frost during bloom, might still negatively influence fruit set of the fewer blossoms (Byers et al., 1990; Costa and Vizzotto, 2000). A preferred alternative approach is using blossom thinners that burn flower parts and prevent fertilization and therefore fruit set (Southwick et al., 1996). The surfactant, Tergitol-TMN-6, significantly reduced fruit set and increased fruit size in ‘Empress’ plums at various rates (7.5 and 12.5 mL·L\textsuperscript{-1}) (Fallahi et al., 2006). Tergitol-TMN-6 is effective over a wide range of phenological stages from full bloom to petal fall, which allows for a longer window of application (Wilkins et al., 2004). The current recommendation for stone fruit is to apply Tergitol-TMN-6 at 75% to 80% full bloom at 7.5–12.5 mL·L\textsuperscript{-1} (Fallahi et al., 2006), but in South Africa, blossom thinners have not been very successful.

A number of chemical thinners are used commercially on pome fruit, e.g., ethephon, 6-benzyladenine (6-BA) and naphthalene acetic acid (NAA) (Byers and Carbaugh, 1991). Ethephon releases ethylene which stimulates fruit abscission (Wertheim, 2000). Ethephon at 250 µL·L\textsuperscript{-1} applied to ‘Victoria’ plums at full bloom did not reduce fruit set, whereas 75 µL·L\textsuperscript{-1} Ethephon combined with 10 µL·L\textsuperscript{-1} NAA applied 27 d after full bloom did reduce fruit set significantly. Both treatments advanced fruit maturity (Meland, 2007). The return bloom the next season, however, was not improved by either treatment (Meland and Birken, 2010). A new chemical thinner currently being evaluated in pome fruit is ACC (Schupp et al., 2012), but its efficacy on Japanese plums is unknown. According to Adams and Yang (1979), ACC is effectively converted to ethylene in apple tissue. Further studies on mung beans confirmed that ACC, a precursor of ethylene, increased the corresponding rate of ethylene production (Yoshii and Imaseki, 1981).

Mechanical thinning is a relatively new development in the stone fruit industry and can be used to remove both flowers and fruitlets (Miller et al., 2011; Theron et al., 2015). Hand thinning could be reduced by mechanical thinning by 28%. In addition, the effect of mechanical thinning is immediate and not influenced by climatic conditions (Martin et al., 2010). Inconsistent results, however, have hampered the successful implementation of mechanical thinning in stone fruit (Reighard and Byers, 2009). Miller et al. (2011), Baugher et al. (2009, 2010) and Schupp et al. (2008) found added...
economic benefits in producing larger peach fruit while reducing follow-up hand thinning when they combined mechanical bloom thinning with green-fruit hand thinning (Miller et al., 2011; Baugher et al., 2009; Baugher et al., 2010; Schupp et al., 2008). The Darwin™ does not thin selectively enough and will therefore not replace hand thinning completely (Miller et al., 2011). More recently De Villiers (2014) evaluated the Darwin 300™ on japanese plums and was able to significantly reduce the time it took to hand thin trees. In two of the three trials on the plums ‘African Rose™’ [cv. ARC PR-4 (PR00-01)] and ‘Laetitia’, it also resulted in an increase in fruit size (De Villiers, 2014), but the tree training system has to be adapted to the machine.

The purpose of this study was to evaluate the efficacy of chemical thinners, i.e., ACC and 6-BA applied at the fruitlet stage to various japanese plum cultivars on fruit set, yield, and fruit quality. ACC is a precursor of ethylene and increases ethylene production (Adams and Yang, 1979), which can lead to leaf drop, therefore 6-BA was included in this study to try and prevent phytotoxicity/ leaf drop possibly induced by the ACC (Zieslin and Gottesman, 1983). The chemical thinning treatments were also combined with mechanical thinning using the Darwin 300™ or hand thinning during bloom on ‘African Rose™’.

Materials and Methods

Plant material and site description for the 2013/2014 season. In the 2013/2014 season, a trial was conducted on the japanese plum cultivar African Rose™ on the farm Sandrivier (33°35’58.0” S, 18°55’40.1” E) near Wellington in the Western Cape, South Africa. The mature, uniform flowering ‘African Rose™’ trees, on Mariana rootstock, were planted in 2009 at a spacing of 3.5 m x 1 m. The planting system used for this orchard is a V-system and trees are trained to a 9-wire hedge with 10% ‘Pioneer’ trees as a cross pollinator.

The cross pollinator was ‘Sunbreeze’ and planted every second flower cluster was removed at full bloom plus ACC 200 L·L⁻¹ as a tank-mix. Nine Darwin 300™ at full bloom plus ACC (600 L·L⁻¹), and 10 Darwin 300™ at full bloom plus ACC (800 L·L⁻¹). For the mechanical thinning treatments, each replicate consisted of five trees with the middle tree used to record data. The tractor speed was 4.8 km.h⁻¹ and rotor speed 160 rpm. All chemical applications were made on 3 Sept. 2014 at a fruitlet diameter of 8–10 mm. Hand thinning was done on 16 Sept. 2014 and trees were harvested on 10, 14, and 17 Nov. 2014.

The ‘Fortune’ and ‘Laetitia’ trials each consisted of six treatments in a randomized complete block design with 10 replicates as follows: 1) an untreated control, 2) 6-BA (100 µL·L⁻¹), 3) ACC (200 µL·L⁻¹), 4) ACC (400 µL·L⁻¹), 5) ACC (600 µL·L⁻¹), and 6) 6-BA (100 µL·L⁻¹) plus ACC (600 µL·L⁻¹) as a tank-mix. All chemical applications were made on 1 Oct. 2014 for ‘Fortune’ and on 3 Oct. 2014 for ‘Laetitia’ at a fruitlet diameter of 8–10 mm. Hand thinning was done on 15 and 17 Oct. 2014 and trees were harvested on 22 and 26 Dec. 2014 and 14 Jan. 2015 for ‘Fortune’ and ‘Laetitia’, respectively.

Treatment application. All the foliar applications were made using a motorized knapsack sprayer (STIHL, Pietermaritzburg, South Africa) when the average fruitlet size was 7–10 mm at a rate of 1000 L·ha⁻¹ under slow drying conditions when the temperature was between 10 and 15 °C. At least one tree was left between the treated trees and a buffer row, where more than one row was needed for the trial, to prevent drift effects. The conditions following the applications were favorable for at least 5 d with temperatures above 18 °C.

Data collection. In all trials, the same data were recorded. After the application of the treatments, a period of at least 2 weeks was allowed for fruitlets to drop. Hand thinning was done according to standard commercial practices during which the largest fruitlets were retained, remaining fruitlets spaced and thinned to the required number per tree. All fruitlets thinned by hand were collected and brought back to the laboratory, weighed and counted. At each commercial harvest date, the yield per tree was recorded. A sample of 30 fruit per harvest was brought to the laboratory for further evaluation. The following was recorded on each fruit: fruit weight, diameter, length, firmness, and the incidence of broken stones. Fruit firmness was determined using the GUSS texture analyzer with a 11-mm tip (GUSS electronic model GS 20; Strand, South Africa), while broken stones were recorded as either present or not. Return bloom was not recorded as all trees flowered profusely the following spring and no visual differences were seen.

Statistical analysis. The data were analyzed using SAS Enterprise guide 5.1 (SAS Institute Inc., Cary, NC) using the linear model procedure and the pairwise t test to determine the least significant difference when the F-statistic indicated significance at P < 0.05. Single df, and orthogonal and polynomial contrasts were fitted where applicable.

Results

Results for the 2013/2014 season: ‘African Rose™’. The highest rate of ACC (500 µL·L⁻¹) significantly reduced the number of fruitlets that had to be thinned by hand during commercial hand thinning compared with the control (Table 1). The increase in ACC rate resulted in a linear decrease in the number of fruitlets that needed hand thinning. 6-BA did not thin significantly, not even at the high rate. The addition of 6-BA to the high rate of ACC did not affect the thinning efficacy (Table 1) and no leaf drop/phytotoxicity was observed in this trial. There were no significant differences in total yield per tree (Table 1) or yield at either of the two harvest dates or harvest distribution (data not shown). There was no significant difference in the average fruit weight from a combined fruit sample from the two harvest dates (Table 1).

Results from the 2014/2015 season: ‘African Rose™’. Both the Darwin 300™ and the hand flower thinning treatment at full bloom as well as all ACC applications significantly reduced the number of fruitlets that had to be thinned by hand during commercial hand thinning compared with the control (Table 2). With increasing ACC rate, a linear decrease in the number of fruitlets that needed hand thinning was found. The combination of the ACC and Darwin 300™ significantly reduced the number of fruitlets that had to be thinned compared with the ACC treatments on their own (P = 0.0028) (Table 2). 6-BA did not result in significant thinning and the addition of 6-BA to the high rate of ACC did not affect the thinning efficacy (Table 2). No leaf drop/phytotoxicity was observed in this trial. All the treatments, except 6-BA, significantly increased the
Table 1. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on hand-thinning requirement, yield per tree, and average fruit weight at harvest in ‘African Rose™’ plum at Sandriver, Wellington District, South Africa (2013/2014).

| Treatment       | Avg number of fruitlets thinned by hand | Avg wt of hand thinned fruitlets (g) | Avg fruit wt (g) over two harvests |
|-----------------|----------------------------------------|-------------------------------------|----------------------------------|
| Control         | 1,799 a                                 | 13.7 bc                             | 54.1 cd                          |
| 6-BA 100 μL-L⁻¹ | 1,868 a                                 | 12.9                                |                                  |
| 6-BA 300 μL-L⁻¹ | 1,747 ab                                | 13.3                                | 52.8                              |
| ACC 150 μL-L⁻¹  | 1,852 a                                 | 14.0                                | 56.7                              |
| ACC 300 μL-L⁻¹  | 1,572 abc                               | 13.9                                | 56.0                              |
| ACC 500 μL-L⁻¹  | 1,424 c                                 | 13.1                                | 55.8                              |
| 6-BA + ACC       | 1,490 be                               | 12.1                                | 52.3                              |

Significance level: 0.0177 least significant difference 5% 302

Significance level 0.0177 0.7402 0.1720

Least significant difference 5% 302

Significance level 0.0177 0.7402 0.1720

6-BA (100 μL-L⁻¹) + ACC (500 μL-L⁻¹).

Table 2. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC), and Darwin 300™ on hand-thinning requirement, fruitlet weight at hand thinning, and yield per tree in ‘African Rose™’ plum at Sandriver, Wellington District, South Africa (2014/2015).

| Treatment       | Avg number of fruitlets thinned by hand | Avg wt of hand thinned fruitlets (g) | Avg fruit wt (g) over two harvests |
|-----------------|----------------------------------------|-------------------------------------|----------------------------------|
| Control         | 2,597 a                                 | 1.4 e                               | 9.9 abc                          |
| Darwin at full bloom | 1,359 c                               | 1.8 c                               | 8.6 cd                           |
| Flower thinning | 1,890 b                                 | 1.7 cd                              | 11.1 a                           |
| 6-BA 100 μL-L⁻¹ | 2,844 a                                 | 1.5 de                              | 11.4 a                           |
| Flower thinning | 1,890 b                                 | 1.7 cd                              | 11.1 a                           |
| 6-BA 100 μL-L⁻¹ | 1,371 c                                 | 1.8 c                               | 10.6 ab                          |
| ACC 400 μL-L⁻¹  | 1,088 cd                                | 1.9 c                               | 11.2 a                           |
| ACC 600 μL-L⁻¹  | 802 de                                  | 1.8 c                               | 8.0 d                            |
| 6-BA + ACC      | 835 bc                                  | 2.0 bc                              | 10.0 abc                         |
| Darwin + ACC 600 μL-L⁻¹ | 650 e                               | 2.3 a                               | 8.9 bcd                          |
| Darwin + ACC 800 μL-L⁻¹ | 527 e                               | 2.1 ab                              | 7.9 d                            |

Significance level: <0.0001 least significant difference 5% 325.88

Significance level 0.0002 0.0002 0.0002

6-BA (100 μL-L⁻¹) + ACC (800 μL-L⁻¹).

The average weight of the thinned fruitlets significantly compared with the control (Table 2). The average weight of the thinned fruitlets for the ACC and Darwin 300™ combination treatments was significantly higher than that of the same ACC rates on their own.

Only the highest rate of ACC (800 μL-L⁻¹) on its own and in combination with the Darwin 300™ reduced the total yield per tree compared with the control (Table 2). There was a quadratic trend in total yield per tree with increasing ACC rate with only the highest rate reducing yield significantly. On average, all treatments altered the harvest distribution compared with the control (Table 3). The percentage of fruit that was harvested during the first harvest for the ACC and the Darwin 300™ combination treatments was significantly higher than that of the control. Almost the opposite could be observed during the third harvest, where the percentage fruit harvested for the untreated control was the highest, but not significantly higher than 6-BA treatment, ACC 400 μL-L⁻¹, and ACC 600 μL-L⁻¹ (Table 3). All the treatments increased the average fruit weight except for 6-BA and again the average fruit weight increased quadratically with the ACC rate until 600 μL-L⁻¹, and ACC 600 μL-L⁻¹ being the highest fruit weight of the ACC treatments (Table 3). Also, the average weight of the two higher ACC rates (600 and 800 μL-L⁻¹) and two ACC and Darwin 300™ combination treatments had significantly larger fruit compared with the rest of the treatments. The average fruit weight at the first harvest increased from the lower to the two higher rates of ACC and the average fruit weight of the ACC treatments at the first harvest was significantly higher than that of the control (data not shown). Broken stone levels were very low, ranging from 0% to 0.12% (data not shown).

The two higher ACC rates and the combination treatment with 6-BA reduced the total yield per tree significantly when compared with the control, whereas the 6-BA and two lower ACC rates did not have any significant effect on the average fruit weight (Table 5). No differences were found in average fruit weight at the first harvest date, whereas the two higher ACC rates and the combination treatment with 6-BA increased the average fruit weight significantly during the second harvest, and there was a linear increase in fruit weight as the ACC rates increased (data not shown). These treatments had no effect on the incidence of broken stones (data not shown).

‘African Rose™’. ‘African Rose™’ is a self-fertile, early Japanese plum (Culdevo, 2009), and therefore sets excessive fruit. In addition, the short fruit development phase tends to result in small fruit size. The highest ACC rate and the combination treatment reduced the total yield significantly (Table 6). The two higher ACC rates and the combination treatment increased average fruit weight significantly compared with the control with a linear increase in fruit weight as the ACC application rate increased (Table 6). No broken stones were observed in any fruit.

Discussion

‘African Rose™’. ‘African Rose™’ is a self-fertile, early Japanese plum (Culdevo, 2009), and therefore sets excessive fruit. In addition, the short fruit development phase tends to result in small fruit size. The highest ACC rate of 500 μL-L⁻¹, both alone or in combination with 6-BA, were the only two treatments that had a significant thinning effect in the first season. This was clear from the number of fruitlets that needed to be hand thinned. Exogenously applied Ethephon increases ethylene levels in plants (Wertheim, 1997), thereby stimulating fruit abscission (Wertheim, 2000). A similar response to ACC, a precursor of ethylene, is expected.
Table 3. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC), and Darwin 300™ on yield distribution and average fruit weight of ‘African Rose™’ plum at Sandrivier, Wellington District, South Africa (2014/2015).

| Treatment          | Percentage of fruit picked at first harvest | Percentage of fruit picked at second harvest | Percentage of fruit picked at third harvest | Avg fruit wt (g) over three harvests |
|--------------------|---------------------------------------------|---------------------------------------------|---------------------------------------------|-------------------------------------|
| Control            | 13.5 c                                      | 26.4<sup>a</sup>                            | 60.1 a                                      | 52.5 c                              |
| Darwin at full bloom| 24.8 bc                                     | 32.7                                        | 42.6 bc                                     | 59.8 b                              |
| Flower thinning    | 25.2 bc                                     | 30.7                                        | 44.1 bc                                     | 57.2 b                              |
| 6-BA 100 μL L<sup>–1</sup> | 19.1 bc                                     | 29.1                                        | 51.8 ab                                     | 52.5 c                              |
| ACC 400 μL L<sup>–1</sup> | 18.3 bc                                     | 34.8                                        | 46.9 abc                                    | 59.5 b                              |
| ACC 600 μL L<sup>–1</sup> | 15.3 c                                      | 33.7                                        | 51.0 ab                                     | 66.1 a                              |
| ACC 800 μL L<sup>–1</sup> | 19.8 bc                                     | 42.3                                        | 37.9 bed                                    | 64.9 a                              |
| 6-BA + ACC<sup>+</sup> | 27.6 abc                                     | 37.2                                        | 35.2 cd                                     | 59.5 b                              |
| Darwin + 600 μL L<sup>–1</sup> | 32.4 c                                      | 34.8                                        | 32.8 cd                                     | 66.2 a                              |
| Darwin + ACC 600 μL L<sup>–1</sup> | 40.1 a                                      | 33.4                                        | 26.5 d                                      | 64.3 a                              |
| Significance level | 0.0161                                      | 0.2523                                      | 0.0017                                      | <0.0001                             |
| Least significant difference 5% | 14.73                                       | —                                           | 15.57                                       | 4.26                                |
| ACC vs. ACC + Darwin | 0.0006                                      | 0.3147                                      | 0.0090                                       | 0.8858                              |
| ACC linear         | 0.8399                                      | 0.1704                                      | 0.2524                                       | 0.0134                              |
| ACC quadratic      | 0.5568                                      | 0.3089                                      | 0.2078                                       | 0.0391                              |
| Control vs. rest   | 0.0455                                      | 0.0556                                      | 0.0016                                       | <0.0001                             |

<sup>6-BA (100 μL L<sup>–1</sup>) + ACC (800 μL L<sup>–1</sup>).</sup>

Table 4. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on hand-thinning requirement, fruitlet weight at hand thinning, and average yield per tree of ‘Fortune’ plum at Sandrivier, Wellington District, South Africa (2014/2015).

| Treatment          | Avg number of fruitlets thinned by hand | Avg wt of thinned fruitlets (g) | Total yield per tree (kg) |
|--------------------|----------------------------------------|-------------------------------|----------------------------|
| Control            | 427 b                                   | 7.8                           | 12.3 a                      |
| 6-BA 500 μL L<sup>–1</sup> | 606 a                                   | 6.8                           | 10.9 a                      |
| ACC 200 μL L<sup>–1</sup> | 451 b                                   | 7.2                           | 12.3 a                      |
| ACC 400 μL L<sup>–1</sup> | 239 c                                   | 7.8                           | 8.7 b                       |
| ACC 600 μL L<sup>–1</sup> | 188 c                                   | 7.4                           | 8.1 b                       |
| 6-BA + ACC<sup>+</sup> | 149 c                                   | 7.9                           | 7.8 b                       |
| Significance level | <0.0001                                 | 0.1404                        | <0.0001                     |
| Least significant difference 5% | 123.64                                 | 1.60                          | 1.60                        |
| Control vs. ACC    | 0.0011                                  | 0.5100                        | <0.0001                     |
| ACC linear         | <0.0001                                 | 0.7600                        | <0.0001                     |
| ACC quadratic      | 0.1362                                  | 0.2597                        | 0.0345                      |

<sup>6-BA (100 μL L<sup>–1</sup>) + ACC (600 μL L<sup>–1</sup>).</sup>

Meland and Birken (2010) found effective thinning of ‘Victoria’ plums after application of Ethephon at 250, 375, and 500 μL L<sup>–1</sup> at full bloom and 125, 250, and 375 μL L<sup>–1</sup> at 10–12 mm fruitlet diameter. Schupp et al. (2012) found promising results when ACC was used to thin ‘Golden Delicious’ apple trees where the thinning effect increased linearly with increasing rate of ACC. In the subsequent season (2014–15), we applied higher rates of ACC (600 and 800 μL L<sup>–1</sup>), but still a large number of fruit had to be thinned by hand. During both seasons, the most effective ACC treatments showed the benefit of early thinning in that the thinned fruitlets were already larger at the time of hand thinning. We included the mechanical and hand flower thinning to reduce fruit number earlier and with the settings chosen for the Darwin 300™ it was expected that using the machine at full bloom would have a similar thinning effect as the 50% hand thinning treatment, and both these treatments resulted in larger fruitlets at commercial hand thinning when compared with the control. De Villiers (2014) also evaluated the Darwin 300™ on ‘African Rose™’ plums with various rotor speeds, viz. 220, 250, and 280 rpm and all treatments significantly reduced the required hand-thinning time compared with the control. Seehuber et al. (2011) also successfully mechanically thinned european plum ‘Ortenauer’. The benefit of early thinning on fruit growth was demonstrated by Grossman and DeJong (1995) on peach trees, therefore, the combination treatments of the Darwin 300™ at full bloom followed by a later ACC application were included in this trial and this enhanced the thinning efficacy and resulted in significantly larger fruitlets at commercial hand thinning compared with the ACC and Darwin 300™ treatments on their own. In both seasons, the 6-BA treatment did not have any thinning effect, which was expected (S. Reynolds, personal communication). Also no leaf drop was observed, therefore, the addition of 6-BA to the ACC did not have any beneficial or negative effects.

During the first season, no significant effects on total yield, harvest distribution, fruit weight were found with any ACC treatments. Therefore, the thinning obtained with the 500 μL L<sup>–1</sup> did not over thin, thus justifying the decision to increase the ACC rates in the second season. However, with the increase in ACC rates in the following season, there was a quadratic effect on the yield with the highest ACC rate of 800 μL L<sup>–1</sup> over thinning and resulting in a significantly lower yield than the control. The yield of the 600 μL L<sup>–1</sup> ACC-treated trees did not differ significantly from the control, thus indicating this as the recommended ACC rate for ‘African Rose™’. The yield of the combination treatment of the Darwin 300™ and ACC 600 μL L<sup>–1</sup> did not differ from the control even though the thinning effect of the combination treatment was significantly higher than the treatments on their own. The Darwin 300™ on its own, and 50% hand flower thinning during bloom did not significantly reduce yield compared with the control. De Villiers (2014) found similar results for total yield when using the Darwin 300™. With the increase in ACC rates in the 2014/2015 season, a linear decrease in yield was observed as the rate of ACC increased, which should make it possible to find the correct rate of ACC depending on the yield required.

The combination treatments between the Darwin 300™ and ACC did advance harvest and almost 30% more fruit was picked at the first harvest date. Fruit firmness was not significantly affected (data not shown), indicating that fruit maturity was advanced by the heavy thinning treatments resulting in advanced harvesting, which is a known response to thinning (Costa and Vizzotto, 2000; Wünsche et al., 2000).

In the 2014/2015 season, all the treatments had a significant and positive effect on fruit size except for the 6-BA treatment. Pavel and DeJong (1993) found that individual fruit size increased in trees with lower crop loads compared with the fruit of unthinned trees and this is a well-known response to fruit thinning (Costa et al., 1983; Costa and Vizzotto, 2000). The Darwin 300™ treatment increased the average fruit weight significantly compared with the control, thus corresponding with what De Villiers (2014) found. The two combination treatments of the Darwin 300™ with ACC 600 and 800 μL L<sup>–1</sup>; and these two ACC rates alone significantly increase fruit size compared with the untreated control, but also more so than the flower thinning treatments alone and the lowest ACC (400 μL L<sup>–1</sup>) rate. The quadratic effect on fruit size that was observed for the ACC-treated trees indicated that the 600 μL L<sup>–1</sup> application had the best effect on fruit size of all the ACC treatments with no further gain above this concentration and again confirming that this should be the recommended rate for ‘African Rose™’. ‘Fortune’. The two higher ACC rates successfully reduced hand fruit thinning as did the combination of ACC and 6-BA. However, in this trial, there was no effect on the average weight of the individual fruitlets thinned by hand. It appears though that these treatments over thinned as the total yield of these treatments was significantly lower compared with the control. It would appear that ‘Fortune’ is more sensitive to ACC than ‘African Rose™’. These treatments did not alter the harvest distribution.
in this trial, but did influence fruit size. The average fruit weight of the ACC treated trees was significantly larger than that of the control trees. This is not surprising as it is well known, as stated earlier, that to achieve fruit of adequate size, regulation of crop load is essential (Day and De Jong, 1998). Even though the lower rate of ACC (200 μL·L⁻¹) did not adequately thin the trees, the 400 μL·L⁻¹ ACC resulted in over thinning, but on average increased fruit size by regulating the crop load (Day and DeJong, 1998), indicating that somewhere between 200 and 400 μL·L⁻¹ ACC might be the recommended thinning rate for ‘Fortune’ plums. There was no need for the addition of 6-BA to prevent leaf drop. As a cautionary note, it should be mentioned that this particular orchard did not yield very well during the particular season.

Laetitia. This cultivar does not set as heavily as African Rose™, therefore, slightly lower rates of ACC were used in a pilot trial in 2013/2014, some promising thinning responses, which led to the full statistical trial the following season. However, the severe leaf drop observed in the pilot trial was important and indicated that applying ACC midday at temperatures exceeding 30 °C could result in phytotoxicity and applications should be made early morning or during the evening at lower temperatures. During the second season, the two higher ACC rates (400 and 600 μL·L⁻¹) significantly thinned fruitlets. 6-BA treatment alone did not have any thinning effect when compared with the control, but had an additive thinning effect in combination with the high ACC rate. Because this ‘Laetitia’ orchard was relatively young and still growing vigorously, the 6-BA could have further stimulated shoot growth (Elving and Cline, 1993; Green et al., 1992) when added to the ACC causing even more competition between the shoots and fruitlets resulting in more severe thinning. The IAA transport out of all the newly released lateral buds might have correlated inhibitory IAA transport from fruit, thus leading to the abscission of some of them (Bangerth, 2000). Unfortunately, we did not monitor shoot growth in our trials. Another reason for the additive effect could be the surfeitants in the 6-BA formulation resulting in more uptake of ACC, but this response was not observed in ‘African Rose™’ or ‘Fortune’.

The total yield of the trees receiving the 400 μL·L⁻¹ ACC application did not differ significantly from the control and would be the recommended rate for ‘Laetitia’ plums as indicated by the significantly lower yield than that of the control and the highest ACC rate application. The two higher ACC concentrations (400 and 600 μL·L⁻¹) had a positive effect on fruit weight. The largest fruit obtained with 600 μL·L⁻¹ might not have compensated for the lower yield, and it is important to find the balance between yield and average fruit size (Njoroge and Reighard, 2008).

Conclusion

We obtained promising fruitlet thinning with ACC on japanese plums. The data indicated that for a self-fertile cultivar like African Rose™, a higher rate of 600 μL·L⁻¹ should be used and possibly also combined with mechanical flower thinning. ‘Laetitia’ could be thinned effectively by using a lower rate of 400 μL·L⁻¹, whereas in the case of ‘Fortune’, even a lower rate could be enough. Although positive results regarding yield and fruit size were obtained for both ‘African Rose™’ and ‘Laetitia’, there is some concern regarding the yield in the ‘Fortune’ trial. Therefore, the recommended use of ACC might be cultivar specific and further trials are needed before final recommendations can be made. In addition, it could be interesting to evaluate earlier application, i.e., at fruitlet diameter of 4–6 mm, especially in ‘African Rose™’ that has a very short fruit growth period. The Darwin 300™ shows promise. The hand thinning required following the Darwin 300™ was ±50% less than that of the untreated control, without negatively influencing yield and with a positive effect on fruit size. No leaf drop/phytotoxicity was observed when ACC was applied during cool conditions, but high temperatures should be avoided.

**Literature Cited**

Adams, D.O. and S.F. Yang. 1979. Ethylene biosynthesis: Identification of 1-aminocyclopropane-1-carboxylic acid as an intermediate in the conversion of methionine to ethylene. Proc. Natl. Acad. of Sci. of Amer. 76(1):170–174.

Baughner, T.A., J.R. Schupp, K.M. Lesser, and K. Hess-Reichard. 2009. Horizontal string blossom thinner reduces labor input and increases fruit size in peach trees trained to open-center systems. HortTechnology 19:755–761.

Baughner, T.A., K. Ellis, J. Remcheck, K. Lesser, J. Schupp, E. Winzele, and K. Reichard. 2010. Mechanical string thinner reduces crop load at variable stages of bloom development of peach and nectarine trees. HortScience 45:1327–1331.

Bangerth, F. 2000. Abscission and thinning of young fruit and their regulation by plant hormones and bioregulators. Plant Growth Regul. 31(1):43–59.

Byers, R.E. and D.H. Carbaugh. 1991. Effect of chemical thinning sprays on apple fruit set. HortTechnology 1:41–48.

Byers, R.E., D.H. Carbaugh, and C.N. Presley. 1990. Influence of bloom thinning and GA3 sprays on flower bud numbers and distribution in peach trees. J. Hort. Res. 29(1):131–135.

Costa, G., C. Giulivo, and A. Ramina. 1983. Effects of the different flower/vegetative buds

---

**Table 5.** Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on yield distribution and average fruit weight at harvest of ‘Fortune’ plum at Sandrivier, Wellington District, South Africa (2014/2015).

| Treatment | Percentage of fruit picked at first harvest | Percentage of fruit picked at second harvest | Avg fruit wt (g) |
|-----------|-------------------------------------------|--------------------------------------------|-----------------|
| Control   | 21.9 a                                     | 78.1 b                                     | 88.7 bc         |
| 6-BA 500 μL·L⁻¹ | 18.4                                      | 81.6                                       | 85.4 c          |
| ACC 200 μL·L⁻¹ | 18.3                                      | 81.7                                       | 91.9 abc        |
| ACC 400 μL·L⁻¹ | 31.2                                      | 68.7                                       | 95.3 ab         |
| ACC 600 μL·L⁻¹ | 29.8                                      | 70.2                                       | 99.9 a          |
| 6-BA + ACC | 27.5                                      | 72.5                                       | 100.4 a         |

Significance level 0.0938

Least significant difference 5% 8.90

**Table 6.** Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on hand-thinning requirement, average weight of thinned fruitlets, yield per tree, and average fruit weight at harvest of ‘Laetitia’ plum at Fransmanskraal, Stellenbosch District, South Africa (2014/2015).

| Treatment | Average number of fruitlets thinned by hand | Average weight of hand thinned fruitlets (g) | Total yield per tree (kg) | Average fruit weight (g) |
|-----------|--------------------------------------------|---------------------------------------------|---------------------------|--------------------------|
| Control   | 385.5                                      | 4.6                                         | 10.7 ab                   | 73.0 c                   |
| 6-BA 500 μL·L⁻¹ | 412 a                                      | 3.9                                         | 11.7 a                    | 73.2 c                   |
| ACC 200 μL·L⁻¹ | 350 a                                      | 3.9                                         | 10.9 ab                   | 74.5 c                   |
| ACC 400 μL·L⁻¹ | 217 b                                      | 3.5                                         | 9.7 bc                    | 87.4 b                   |
| ACC 600 μL·L⁻¹ | 171 b                                      | 3.7                                         | 8.2 c                     | 91.5 b                   |
| 6-BA + ACC | 70 c                                       | 3.9                                         | 5.8                       | 97.6 a                   |

Significance level <0.0001

Least significant difference 5% 0.0001

Control vs. ACC <0.0001

ACC linear 0.0025

ACC quadratic 0.2661

6-BA (100 μL·L⁻¹) + ACC (600 μL·L⁻¹).
ratio on the peach fruit abscission and growth. Acta Hort. 139:149–160.
Costa, G. and G. Vizzotto. 2000. Fruit thinning of peach trees. Plant Growth Regulat. 31:113–119.
Culdevco. 2009. <http://www.culdevco.co.za/images/stories/STONE/AFRICANROSEARCP4-Releasedin2009.pdf>.
Day, K.R. and T.M. De Jong. 1998. Improving fruit size: Thinning and girdling nectarines, peaches, and plums. The Compact Fruit. Tree 32(2):1–6. De Jong, T. and Y.L. Grossman. 1994. A supply and demand approach to modeling annual reproductive and vegetative growth of deciduous fruit trees. HortScience 29:1435–1442.
De Villiers, M.H.J. 2014. Mechanical and chemical thinning of stone fruit. MSc Agr thesis, Stellenbosch University, South Africa.
Elfving, D.C. and R.A. Cline. 1993. Benzyladenine and other chemicals for thinning Empire apple trees. J. Amer. Soc. Hort. Sci. 118:593–598.
Fallahi, E., B. Fallahi, J.R. McFerson, R.E. Beyers, R.C. Ebel, R.T. Boozer, J. Pitts, and B.S. Wilkins. 2006. Tergitol-TMN-6 surfactant is an effective blossom thinner for stone fruits. HortScience 41:1243–1248.
González-Rossia, D., M. Juan, C. Reig, and M. Agusti. 2006. The inhibition of flowering by means of gibberellic acid application reduces the cost of hand thinning in Japanese plums (Prunus salicina Lindl.). Sci. Hort. 110(4):319–323.
Green, D.W., W.R. Autoio, J.A. Erf, and Z.Y. Mao. 1992. Mode of action of benzyladenine when used as a chemical thinner on apples. J. Amer. Soc. Hort. Sci. 117:775–779.
Grossman, Y.L. and T. De Jong. 1995. Maximum fruit growth potential and seasonal patterns of resource dynamics during peach growth. Ann. Bot. 75:553–560.
Martin, B., A. Torregrosa, and J. Garcia Brunton. 2010. Post-bloom thinning of peaches for canning with hand-held mechanical devices. Sci. Hort. 125(4):658–665.
Meland, M. 2007. Efficacy of chemical bloom thinning agents to European plums. Acta Agr. Scand. B-S P 57(3):235–242.
Meland, M. and E. Birken. 2010. Ethephon as a blossom and fruitlet thinner affects crop load, fruit weight and fruit quality of the European plum cultivar ‘Jubileum’. Acta Hort. 884:315–322.
Miller, S.S., J.R. Schupp, T.A. Baugher, and S.D. Wolford. 2011. Performance of mechanical thinners for bloom or green fruit thinning in peaches. HortScience 46:43–51.
Njoroge, S.M.C. and G.L. Reighard. 2008. Thinning time during stage I and fruit spacing influences fruit size of ‘Contender’ peach. Sci. Hort. 115(4):352–359.
Pavel, E. and T. De Jong. 1993. Source-and sink-limited growth periods of developing peach fruits indicated by relative growth rate analysis. J. Amer. Soc. Hort. Sci. 118:820–824.
Reighard, G. and R. Byers. 2009. Peach thinning. Department of Horticulture, Clemson University. Clemson, SC, retrieved 22 Nov.
Schupp, J.R., T.M. Kon, and H.E. Winzeler. 2012. 1-aminocyclopropane carboxylic acid shows promise as a chemical thinner for apple. HortScience 47:1308–1311.
Schupp, J.R., T.A. Baugher, S.S. Miller, R.M. Harsh, and K.M. Lesser. 2008. Mechanical thinning of peach and apple trees reduces labor input and increases fruit size. HortTechnology 18:660–670.
Seehuber, C., L. Damerow, and M. Blanke. 2011. Regulation of source: Sink relationship, fruit set, fruit growth and fruit quality in European plum (Prunus domestica L.)—Using thinning for crop management. Plant Growth Regulat. 65(2):335–341.
Southwick, S.M., K.G. Weis, and J.T. Yeager. 1996. Bloom thinning ‘Loadel’ cling peach with a surfactant. J. Amer. Soc. Hort. Sci. 121:334–338.
Theron, K.I., M.H.J. De Villiers, and W.J. Steyn. 2015. Is mechanical blossom thinning a viable alternative to hand thinning for stone fruit? S.A. Fruit J. (June/July):72–73.
Wertheim, S.J. 1997. Chemical thinning of deciduous fruit trees. Acta Hort. 463:445–462.
Wertheim, S.J. 2000. Developments in the chemical thinning of apple and pear. Plant Growth Regulat. 31:85–100.
Wilkins, B.S., R.C. Ebel, W.A. Dozier, J. Pitts, and R. Boozer. 2004. Tergitol TMN-6 for thinning peach blossoms. HortScience 39:1611–1613.
Wünsche, J.N., J.W. Palmer, and D.H. Greer. 2000. Effects of crop load on fruiting and gas-exchange characteristics of ‘Braeburn’/M.26 apple trees at full canopy. J. Amer. Soc. Hort. Sci. 125:93–99.
Yoshii, H. and H. Imaseki. 1981. Biosynthesis of auxin-induced ethylene. Effects of indole-3-acetic acid, benzyladenine and abscisic acid on endogenous levels of 1-aminocyclopropane-1-carboxylic acid (ACC) and ACC synthase. Plant Cell Physiol. 22(3):369–379.
Zieslin, N. and V. Gottesman. 1983. Involvement of ethylene in the abscission of flowers and petals of Leptospermum scoparium. Physiol. Plant. 58(1):114–118.