New chemical thinning strategies for stone fruit

By

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the authorship owner thereof and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: December 2015

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SUMMARY

Thinning of stone fruit, just as in any other deciduous fruit crop, plays an important role in producing fruit of the right size and quality. Hand thinning is highly labor intensive and time consuming, thus an alternative method of thinning is important to the industry. Chemical and mechanical thinning either alone or in combination could be the alternative.

Two chemicals, 1-aminocyclopropane-1-carboxylic acid (ACC) and 6-benzyladenine (6-BA) were evaluated on Japanese plums, cling peaches and nectarines. In addition, the Darwin 300™, a mechanical string thinner, was also included in trials on early maturing 'Alpine' nectarine and 'African Rose™' plum. In all trials the objective was to reduce the required hand thinning during commercial hand thinning without compromising on yield and fruit quality.

In Japanese plums we were able to reduce the hand thinning requirement significantly with both the ACC thinning and mechanical thinning strategies. Regarding ACC, cultivars differed in their sensitivity to the chemical and the recommended rate will differ for cultivars. ACC consistently reduced the required hand thinning linearly with increasing rate. The recommended rate of ACC for 'African Rose™' is 600 $\mu l.L^{-1}$ and for 'Laetitia' 400 $\mu l.L^{-1}$. For 'Fortune' a recommended rate could not be determined at this stage, thus further trials should be conducted. The Darwin 300™ reduced hand thinning significantly without reducing the yield significantly. Combining the Darwin 300™ with ACC 600 $\mu l \cdot L^{-1}$ in 'African Rose™' gave promising results with regard to hand thinning requirement and fruit size, without reducing yield efficiency significantly. No leaf drop was observed on Japanese plums, except in the pilot trial when applications were made at high temperatures, which should therefore be avoided.

ACC was effective as thinning agent in cling peaches. In 'Keisie', the results were positive during both seasons, and ACC reduced the hand thinning requirement without reducing yield efficiency. The recommended rate of ACC for 'Keisie' is 600 $\mu l.L^{-1}$. Slight leaf drop was observed. In 'Sandvliet', there was a significant reduction in fruit set, without reducing the required hand thinning. The reduction in fruit set led to a significant reduction in yield. Severe leaf drop was observed, indicating that cultivars differ in sensitivity to ACC. ACC would not currently be recommended for 'Sandvliet'.

In nectarines, ACC only thinned 'Turquoise' but not 'Alpine' or 'August Red' at the rates and phenological stage used, again indicating cultivar differences in sensitivity. In

‘Turquoise’, the highest ACC rate (500 µl·L^{-1}) reduced fruit set per tagged shoot, as well as the hand thinning requirement, but this rate also reduced the total yield. The Darwin 300™ evaluated on ‘Alpine’ reduced fruit set significantly and the hand thinning requirement without reducing yield efficiency, indicating that mechanical thinning is a viable option in nectarines. Slight leaf drop was observed in all nectarine trials and ACC would not currently be recommended for nectarines. 6-BA was included to combat ACC-induced leaf drop and was partially successful. The reason for the differences observed in response to ACC between cling peaches and plums on the one hand, and nectarines on the other, cannot currently be explained.

OPSOMMING

Uitdun van steenvrugte, net soos vir enige ander sagtevrugte soort, speel 'n belangrike rol in die produksie van vrugte met die regte grootte en gehalte. Uitdun van steenvrugte is hoogs arbeidsintensief en tydrowend, dus is dit belangrik om ŉ alternatief te vind vir die bedryf. Chemiese of meganiese uitdunning alleen of in kombinasie kan die alternatiewe wees.

Twee middels, 1-aminosiklopropaan-1-karboksielsuur (ACC) en 6-bensieladenien (6-BA) is geëvalueer op Japanese pruime, taaipitperskes en nektariens. Daarby is die Darwin 300™, ŉ meganiese uitdunmasjien, ingesluit vir twee vroeë kultivars, nl. Alpine nektarien en African Rose™ pruim. Die doel van die proewe was om handuitdunning tydens kommersiële handuitdun te verminder, sonder om die opbrengs en vrugkwaliteit negatief te beïnvloed.

Vir Japanese pruime kon ons die nodige handuitdunning beduidend verminder met beide die ACC en meganiese uitdun strategieë. Daar was wel ŉ verskil tussen die kultivars se sensitiwiteit teenoor ACC en die aanbevole konsentrasie sal verskil tussen kultivars. ACC het die benodigde handuitdunning vir al drie kultivars lineêr verminder met ŉ toename in konsentrasie. Die aanbevole konsentrasie van ACC vir ‘African Rose ™’ is 600 $\mu l.L^{-1}$ en vir ‘Laetitia’ 400 $\mu l.L^{-1}$. Vir ‘Fortune’ kan daar nog nie op hierdie stadium 'n konsentrasie aanbeveling gemaak word nie. Die Darwin 300™ behandeling het die benodigde handuitdunning beduidend verminder sonder om die opbrengs te beïnvloed. Die kombinasie van die Darwin 300 ™ met ACC 600 $\mu l.L^{-1}$ het ook goeie resultate opgelewer wat handuitdunning en vruggrootte aanbetref sonder om die opbrengsdoeltreffendheid te verlaag. Geen blaarval was opgemerk by die pruime nie, behalwe in ŉ voorlopige proef toe die ACC toegedien is by hoë temperature, wat dus vermy moet word.

Die effektiwiteit van ACC as uitdunmiddel van taaipitperskes was belowend. Vir ‘Keisie’ was die resultate positief vir beide seisoene, en ACC het handuitdunning verminder sonder om die opbrengs te beïnvloed. Die aanbevole ACC konsentrasie vir ‘Keisie’ is 600 $\mu l.L^{-1}$. Effense blaarval is wel waargeneem. Vir ‘Sandvliet’ was daar 'n beduidende vermindering in vrugset, sonder dat handuitdunning verminder is. Daar was ook 'n beduidende afname in opbrengs en erge blaarval in die proef waargeneem. ACC sal tans nie aanbeveel word vir 'Sandvliet’ nie.

Met nektariens het ACC net ‘n uitduneffek op ‘Turquoise’ getoon, maar nie teen die aangewende dosisse en ontwikkelingstadium op ‘Alpine’ of ‘Augustus Red’ nie. Dit dui daarop dat ACC kultivarspesifiek mag wees. In ‘Turquoise’ het die hoogste konsentrasie (500

μl.L^{-1}) vrugset van gemerkte lote en die handuitdunning verminder, maar ook die totale opbrengs. Die Darwin 300 ™ het die vrugset van 'Alpine' asook die benodigde handuitdunning aansienlik verminder sonder om die opbrengs te verlaag. Effense blaarval was opgemerk in alle nektarien proewe. ACC sal nie aanbeveel word as uitdunmiddel vir nektariens nie. 6-BA was in die studie ingesluit om ACC-geïnduseerde blaarval teen te werk en was slegs gedeeltelik suksesvol. Die rede vir die verskille in respons tot ACC tussen pruime, perskes en nektariens kan nie tans verklaar word nie.

NOTE

This thesis is a compilation of chapters, starting with a literature review, followed by three research papers. Each paper is prepared as a scientific paper for submission to *HortScience*. Repetition or duplication between papers might therefore be necessary.

TABLE OF CONTENTS

GENERAL INTRODUCTION

The South African deciduous fruit industry consists of pome- and stone fruit as well as table grapes. The stone fruit industry of South Africa consists of approximately 18 000 hectares of peaches, plums and nectarines (HORTGRO, 2014). It is an export orientated industry with large volumes being exported annually, therefore fruit of adequate size and good quality is key (NAMC, 2007). Permanent labor is mainly used, but seasonal labor employed on a contract basis also plays an important role in the success of producing fruit of export quality (NAMC, 2007). With the consistent increase in labor costs in South Africa (Pela, 2015) alternative strategies to manage the production costs better is being researched.

Alternative thinning strategies are important for the stone fruit industry, because thinning is highly labor intensive and still mostly done by hand. Annual cropping is important and this can be achieved through thinning. By adjusting the number of fruit on the tree, the remaining fruit will develop to the size which is commercially viable (Njoroge and Reighard, 2008). Chemical and mechanical thinning is considered the alternatives to hand thinning and reducing production costs (Rosa et al., 2008).

The current literature was evaluated and indicates that a lot needs to be done to establish chemical and mechanical thinning as alternatives for hand thinning. Mechanical thinning is a relatively new development in the stone fruit industry and can be used to remove both flowers and fruitlets (Costa and Vizzotto, 2000). Chemical thinning is not always considered the best option (Schupp et al., 2008) because of the impact it might have on the environment. Existing chemical thinners e.g. gibberellic acid used on stone fruit can be applied to reduce flower intensity in the subsequent season (Southwick et al., 1996). This is not the ideal way to thin, because of the possibility of frost or bad weather resulting in low fruit set in the following season (Byers et al., 1990). Given the option, growers would much rather thin their trees in the current season when the flower density and quality of the trees are known (Byers et al., 1990). Here the option is to use caustic chemicals during bloom, however this method is often inconsistent and erratic (Greene et al., 2001). It is optimal for growers to thin fruitlets after bloom as they can first evaluate fruit set before any form of thinning agent is applied (Meland, 2007).

The purpose of this study was to evaluate the efficacy of new chemical thinning strategies, i.e. 1-aminocyclopropane-1-carboxylic acid (ACC) and 6-benzyladenine (6-BA) applied at the fruitlet stage to various Japanese plum, cling peach and nectarine cultivars on fruit set, yield and fruit quality. Previous studies done on apples with ACC gave promising results (Schupp et al., 2012). 6-BA is also a well-known growth stimulator used to thin pome fruit (Byers and Carbaugh, 1991) and will be included in this study, because ACC, being a precursor of ethylene and therefore increases ethylene production (Adams and Yang, 1979), could lead to leaf drop. The chemical thinning treatments were also combined with mechanical thinning utilizing the Darwin 300™ or hand flower thinning on early maturing Japanese plums and nectarines.

In Paper 1 we report on the efficacy of chemical and mechanical thinning of Japanese plums. In the 2013/2014 season trials were conducted with ACC and 6-BA on 'African Rose™' and 'Laetitia' on the farm Sandrivier, near Wellington, South Africa. In 2014/2015 the Darwin 300™ was utilized on African Rose™ in order to thin this early maturing cultivar earlier. In addition the chemicals were evaluated on 'Fortune' and 'Laetitia'.

In Paper 2 we report on the efficacy of ACC and 6-BA on two well-known cling peach cultivars, Keisie (2013/2014 and 2014/2015) on the farm Jagerskraal in the Warm Bokkeveld, South Africa and Sandvliet (2014/2015) on the farm Lucerne, near Bonnievale, South Africa.

In Paper 3 we report on the efficacy of chemical and mechanical thinning of nectarines. In the 2013/2014 season a trial with ACC and 6-BA was conducted on the cultivar Turquoise on the farm Vreeland in the Warm Bokkeveld, South Africa. In the 2014/2015 season the Darwin 300™ and hand flower thinning was included on early maturing 'Alpine' nectarines on the farm Swartdam, near Riebeek-Kasteel, South Africa. Another chemical trial with ACC and 6-BA was conducted in 2014/2015 on a late cultivar August Red on the farm Bo-Bokfontein in the Koue Bokkeveld, South Africa.

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 (abstr.).

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

Byers, R., D. Carbaugh, and C. Presley. 1990. The influence of bloom thinning and GA3 sprays on flower bud numbers and distribution in peach trees. J. Hortic. Sci. 65(2):143-150.

Costa, G. and G. Vizzotto. 2000. Fruit thinning of peach trees. Plant Growth Regul. 31:113–119.

Greene, D.W., K.I. Hauschild, and J. Krupa. 2001. Effect of blossom thinners on fruit set and fruit size of peaches. HortTechnology 11(2):179-183.

HORTGRO. 2014. http://www.hortgro.co.za/market-intelligence-statistics/key-deciduous-fruit-statistics/

Meland, M., 2007. Efficacy of chemical bloom thinning agents to European plums. Acta Agr. Scand. B-S P 57(3):235–242.

NAMC (National Agricultural Marketing Council). 2007. http://www.namc.co.za

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.

Pela. M. Department of Labour. 2015/2016. Labour Minister Oliphant increases farmworkers minimum wage by 7.7 percent in 2015/16. http://www.labour.gov.za/DOL/media-desk/media-statements/2015/labour-minister-oliphant-increases-farmworkers-minimum-wage-by-7-7-percent-in-2015-16/?searchterm=farmworkers.

Rosa, U.A, K.G. Cheetancheri, C.J. Gliever, S.H. Lee, J. Thompson, and D.C. Slaughter. 2008. An electro-mechanical limb shaker for fruit thinning. Comput. Electron. AGR. 61:213-221.

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 labour input and increases fruit size. HortTechnology 18(4):660–670.

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(9):1308-1311.

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(2):334–338.

LITERATURE REVIEW: Thinning of Stone Fruit

Table of contents

Introduction

South Africa is an important role-player in the international deciduous fruit markets. In the past, labor cost in South Africa was relatively low compared to other fruit producing countries, but has recently increased and will keep on escalating (Pela, 2015). Stone fruit production is highly labor intensive and the practices where labor input can be decreased are scarce. One such practice where labor input can be reduced is fruit thinning.

Fruit abscission is the natural way of reducing crop load on a tree, but fruit abscission alone is usually not sufficient to reduce fruit numbers in commercial fruit production (Bangerth, 2000). Hand thinning is the oldest and still the most widely used means to reduce crop load in stone fruit. As mentioned before, labor cost in stone fruit production is very high and hand thinning is largely responsible for this (Baugher et al., 2009). In the past, various mechanical and chemical thinning strategies have been evaluated, all of which have some advantages and some disadvantages, but few were efficient enough to replace hand thinning.

In this literature study the process of abscission and the different thinning techniques available for stone fruit will be briefly reviewed.

Fruit abscission

General physiology. A change in the abscission zone at the pedicel base of flowers or fruit is responsible for the natural abscission of flowers and fruitlets in deciduous fruit trees (Addicott, 1970). Ethylene and auxin are the two most important hormones involved in the stimulation and inhibition of fruit abscission. It is known that ethylene stimulates abscission, but if sufficient auxin is translocated from the fruit across the abscission zone, no fruit drop will occur (Wertheim, 1997). The stimulation of flower or fruit abscission occurs when pollination and subsequent processes are inhibited due to hormonal changes in the fruit. The biggest increase in ethylene production in fruitlets occurs when the endosperm in the developing seed is consumed by the growing embryo (Wertheim, 1997). During this latter stage of development, the production of other hormones tends to decrease and an increase in abscission occurs (Wertheim, 1997).

Young fruit drop is due to signals exerted by older, more mature fruit (Bangerth, 2000). These signals are related to the uni-directional transport of indole-3-acetic-acid (IAA). IAA from the older, more mature fruit inhibits IAA transport from the younger fruit and this mechanism is responsible for triggering the abscission of the younger fruit (Bangerth, 2000). In addition, the IAA transported from competing bourse shoots in clusters in pome fruit can also inhibit the IAA transport from fruitlets (Bangerth, 2000).

Role of ethylene. When apple tissue was incubated in air and fed with [U-^{35}] methionine, it produced more ethylene than apple tissue incubated in nitrogen, thus indicating a need for oxygen for the conversion of methionine to ethylene (Adams and Yang, 1979). Adams and Yang (1979) also found that apple tissue was able to convert 1-aminocyclopropane-1-carboxylic acid (ACC) to ethylene. They hypothesized that if ACC is an intermediate in the conversion of methionine to ethylene, then the addition of unlabeled ACC should dilute the incorporation of radioactivity from methionine in ethylene, but the incorporation of radioactivity from ACC in ethylene should be less affected by the administration of unlabeled methionine. They proved this hypothesis and confirmed previous studies that methionine is converted to MeSRib (5-methyl-thioribose) and ACC via S-adenosylmethionine (SAM) MeSAdo(5'-methylthioadenosine), which is sensitive to aminoethoxyvinyglycine (AVG) inhibition, but the conversion of ACC to ethylene is not affected by AVG. On the contrary, AVG stimulated the conversion of ACC to ethylene. They explained this effect in that AVG possibly inhibited the conversion of endogenous methionine to ACC, thus resulting in less ACC and thus less dilution of the labelled ACC.

Yoshii and Imaseki (1981) using mung beans, confirmed that 6-benzyladenine (6-BA), a synergistic stimulator of auxin induced ethylene production, increased the amount of ACC parallel to the rate of ethylene production when IAA was present, but did not increase the ACC content in the absence of IAA, while ethylene production was stimulated significantly by 6-BA. Yoshii and Imaseki (1981) also found that abscisic acid (ABA) inhibited ACC production.

Rasori et al. (2002) showed that two peach genes, Pp-ETR1 and Pp-ERS1, that are homologous to the Arabidopsis ethylene receptor genes ETR1 and ERS1, play an important role in various phenological stages such as fruit development, fruit ripening and fruitlet abscission. By performing a quantitative RT-PCR, Rasori et al. (2002) found that the level of Pp-ETR1 transcripts remained unchanged during all the developmental stages examined, and Pp-ERS1 mRNA increased in the leaf and fruitlet activated abscission zones.

Importance of thinning

In the stone fruit industry, just as in any other deciduous fruit industry, annual cropping is very important and it is believed that this can be achieved through flower and fruitlet thinning. Peach trees tend to set excessive fruit, therefore producing small fruit and enhancing biennial bearing, reducing tree vigor and making the tree more susceptible to diseases (Reighard and Byers, 2009). Deciduous fruit trees often cannot supply all the fruit with assimilates up until harvest despite the natural abscission of fruit (Damerow and Blanke, 2009).

By adjusting the number of fruit on the tree, the remaining fruit will develop to a commercially viable size (Njoroge and Reighard, 2008). The time of thinning, however, will play a role in the success of thinning. According to Njoroge and Reighard (2008), there are various times that thinning can be applied, i.e. pre-bloom, full bloom and post-bloom, and the cheapest and earliest method of thinning is pruning. However, even when the trees are properly pruned, they still set too many fruit to develop adequate size (DeJong and Grossman, 1994).

Fruit growth of stone fruit can be divided into three main stages (Day and DeJong, 1998). Stage I is a stage of rapid growth after fruit set at the beginning of the season when cell division and expansion is stimulated in the remaining fruit. This is followed by a slow growing phase, stage II, during which pit-hardening takes place, and ends with stage III, again a period of rapid growth featuring cell expansion and maturation of the mesocarp (Costa and Vizzotto, 2000). Thinning fruit during stage I is considered to be optimal since final cell number will be established during this stage when fruit grow logarithmically and it is considered essential to optimize fruit growth during this time, otherwise a potential loss in fruit size can occur (Day and DeJong, 1998). In addition, the time of thinning is critical, as competition for assimilates needs to be reduced as soon as possible for remaining fruit to benefit from the reduced crop load (Stover, 2000).

According to Costa and Vizzotto (2000), the severity of thinning as well as the timing is closely linked to the reproductive and vegetative performance of the tree. During stage II, pit-hardening requires a lot of assimilates for endocarp lignification, even though fruit size does not rapidly increase during this stage. Thus delaying fruit thinning until this stage means that a lot of assimilates will not be utilized for fruit size (Weinberger, 1941). However, one advantage of delaying the thinning is to better identify which fruit will be the largest on a particular shoot, but it is still important not to wait longer than necessary to thin (Day and DeJong, 1998). According to Southwick and Glozer (2000), if fruit thinning is delayed up to 30 days after full bloom (DAFB), it offers the opportunity to thin fruit selectively. However, the disadvantage of this delay is early competition between fruitlets that may compromise the size of the remaining fruit after thinning (Southwick and Glozer, 2000).

Hand thinning

Hand thinning is very costly and therefore growers postpone it to identify the larger fruit on the tree and then thin selectively. They save money, but during this time, source limitations may lead to lower yields and smaller fruit. However, an increase in fruit size is not always favorable, as it does not always compensate for the decrease in yield (Njoroge and Reighard, 2008).

Njoroge and Reighard (2008) found that fruit of peach trees thinned 0 to10 DAFB had a significantly higher soluble solids concentration (SSC) than fruit of trees thinned at 20, 30 or 40 DAFB. Fruit from trees thinned 40 DAFB had significantly higher SSC than fruit of trees thinned 30 DAFB, thus there was no clear pattern in the different times of thinning in relation to SSC. They confirmed this again when they repeated the trial the following year and found that the SSC was significantly higher in fruit of trees thinned at 0 to10 and 30 DAFB compared to fruit from trees thinned at 20 DAFB (Njoroge and Reighard, 2008). Njoroge and Reighard (2008) found that when trees were hand thinned at 0 to10 DAFB, it resulted in significantly larger mean fruit weight and diameter than when trees were thinned later. They found no significant difference in fruit weight when trees were thinned 30 and 40 DAFB.

Mechanical thinning

Mechanical thinning is a relatively new development in the stone fruit industry and can be used to remove both flowers and fruitlets (Costa and Vizzotto, 2000). Mechanical thinning is an environmentally friendly thinning strategy and therefore of high importance to the industry. Miller et al. (2011) found that mechanical thinning could be an alternative to hand thinning and some unreliable chemical thinning agents in peach production. In the past, various mechanical thinning methods have been evaluated, for example using specialized brushes, dragging rope, high pressure water jets and also a mechanical shaker. It takes approximately 20 to 30 minutes to hand thin an average peach tree and one of the main reasons why mechanical thinning is preferred over chemical thinning is that with mechanical thinning results are immediately visible (Martin et al., 2010).

Mechanical shakers used to thin peach trees at the fruitlet stage obtained similar results over a 6-year period to trees thinned by hand (Powell et al., 1975). Powel et al. (1975) found that the mechanical shaker they used was successful in that it did not damage the trees; however, using the shaker to thin fruitlets had a distinct disadvantage because it used the momentum of the fruit, thus removing the larger fruitlets. This was confirmed by Berlage and Langmo (1982) with their inertia trunk shaker. Even though they did reduce the time it took to hand thin the trees significantly, the yield was also reduced significantly.

Schupp et al. (2008) found that the Darwin 300™ could reduce the number of flowers by 30-46% and reduced the follow-up hand thinning time by 24-48% on high density "V" trained peach trees. Schupp et al. (2008) also reduced the follow-up hand thinning time between 54 and 81% using a drum shaker and increased the percentage of fruit in larger size categories by 35%. They concluded that mechanically thinning trees at 20% bloom yielded a larger crop than trees thinned mechanically at 80% bloom (Schupp et al., 2008).

Damerow and Blanke (2009) developed a mechanical thinner with three horizontal string rotors, the BAUM or Uni-Bonn machine. They found that they were able to remove enough flowers from apple trees, but the device did cause hail-like damage to the leaves. Martin et al. (2010) evaluated two different hand-held thinning devices, the first being an electrical fruitlet thinner with six rotating fingers and the second a pneumatic hand-held shaker. These two devices did not significantly affect yield compared to commercial hand thinning. Crop load was reduced by all three techniques by approximately 38% and increased average fruit weight by approximately 47%. The pneumatic shaker did appear effective at first, but did not remove enough fruitlets. They concluded that using the device with the six rotating fingers with follow-up hand-thinning produced the larger and better fruit (Martin et al., 2010). Miller et al. (2011) effectively thinned peach flowers in the upper canopy at 80% full bloom using the Darwin™ string thinner, but it did not thin effectively in the lower canopy. Miller et al. (2011) like Baugher et al. (2009; 2010) and Schupp et al. (2008) proved that there is added economic benefits in producing larger fruit and reducing follow-up hand-thinning when they combined mechanical bloom thinning with hand fruitlet thinning (Baugher et al., 2009; 2010).

More recently, De Villiers (2014) evaluated the Darwin 300™ on three nectarines, viz. 'Zephyr', 'Summer Fire' and 'Royal Sun' and found promising results regarding the time it took to thin the trees. He evaluated various rotor speeds, viz. 200, 220 and 240 rpm at full bloom with a constant tractor speed of 4.8 $km \cdot h^{-1}$. There was no significant difference between the different rotor speeds for the time required for hand thinning, but for 'Zephyr' the time required to hand thin the trees was reduced by 43% in the first season and by 33% in the second season. Similar results were obtained for 'Summer Fire' and 'Royal Sun'. De Villiers (2014) did, however, notice a linear decrease in yield with increasing rotor speed for all three cultivars. With the decrease in yield, the average fruit size of 'Zephyr' and 'Summer Fire' increased. In 'Zephyr', this increase in size was also associated with an increase in the incidence of fruit cracking.

De Villiers (2014) did similar studies with the Darwin 300™ on the Japanese plums 'African Rose™', 'Laetitia' and 'African Delight™' and found a significant reduction in the time required to thin trees. The rotor speeds were 220, 250 and 280 rpm for 'African Rose™' and 'Laetitia' and 250, 280 and 310 rpm for 'African Delight™' as plums are more difficult to thin mechanically (A. Betz, personal communication). Yield efficiency was reduced in the case of African Delight™, but not in the other two cultivars. Increases in fruit size and fruit quality were found in 'African Rose™' and 'Laetitia'.

Chemical thinning

Although chemical thinning of pome fruit is relatively successful, this is not the case for peaches (Greene et al., 2001). Therefore, there is still a need for a chemical thinner that is more cost effective than hand thinning in the stone fruit industry. There are generally three chemical thinning options. The first entails the reduction of flowers in the subsequent season, the second the reduction of flowers in the current season and the third preferred option is thinning fruitlets when fruit set is known prior to thinning taking place (Day and DeJong, 1998).

Reducing flowers in subsequent season. Gibberellic acid (GA_3) can reduce the peach crop in subsequent seasons when applied in the current season during flower bud differentiation (Costa and Vizzotto, 2000). It can also have a positive effect on fruit quality in the season of application (De Villiers, 2014). GAs are translocated from the fruit to nearby nodes and inhibit the initiation of new floral primordial (Webster and Spencer, 2000). Therefore, applying GA_3 during flower induction will partially reduce flowering and indirectly reduce the number of fruit, which will lead to a reduction in hand thinning costs (Gonzalez-Rossia et al., 2006). The reason why GA application has not become the alternative to hand thinning is because of the possibility of frost or bad weather resulting in low fruit set in the following season (Byers et al., 1990).

Coetzee and Theron (1999b) found that Ralex®, (GA_3) effectively thinned 'Sunlite' nectarines. They applied Ralex® at, 90, 120, 150 and 180 $mg{\cdot}L^{-1}$ as four treatments either four weeks before harvest (8 November) or four treatments between the first and second harvest dates (11 December) and a double application of 90 $mg{\cdot}L^{-1}$ 4 weeks before harvest and during harvest. All the treatments reduced the number of reproductive buds and increased vegetative bud density in the subsequent season. The earlier application over thinned and no interaction occurred between concentration and the time of application. Hand thinning was still required, despite the reduction in reproductive buds, to space fruit correctly on the shoots.

GA_3 applications during flower initiation reduced flowering while later applications were not effective (Southwick and Glozer, 2000). Peaches develop three buds per node; the two outer buds are reproductive while the middle bud is vegetative. Early GA_3 applications caused the outer reproductive buds to develop as vegetative buds, causing a reduction in flowering (Southwick and Glozer, 2000). The later GA_3 applications, however, did not have the same effect on the outer reproductive buds and did not cause a reduction in flowering (Southwick and Glozer, 2000).

Southwick and Glozer (2000) compared GA_3, GA_4, and GA_7 at concentrations of 30 and 60 $mg{\cdot}L^{-1}$ and at three different dates from 8 May to 8 June (northern hemisphere) on ‘Royal/Blenheim’ apricots. Flowering was only reduced by GA_4 at 60 $mg{\cdot}L^{-1}$. However, GA_7 at both concentrations unexpectedly increased flowering and GA_3 increased flowering at 30 $mg{\cdot}L^{-1}$. This was also previously found by Southwick et al. (1995) on ‘Patterson’ apricot with a low GA_3 concentration of 10 $mg{\cdot}L^{-1}$. Southwick and Glozer (2000) concluded that GA-treated trees often produced yields similar to hand thinned trees, but also sometimes larger due to the early reduction in competition. Southwick and Fritts (1994) also evaluated the impact of GA treatments on fruit firmness and found that in most stone fruit cultivars, an increase in fruit firmness occurred in the season of application.

The sensitivity to GA treatments is affected by tree age and vigor. Since younger trees are more sensitive to GA, it is recommendable to only treat more mature trees with GAs (Southwick and Fritts, 1994). Southwick and Fritts (1994) also found that using GA sprays for consecutive seasons may cause a decline in the ability of a tree to flower. Despite these added risks to the potential yield, using GA applications may become more attractive because of the continuous increase in labor cost (Southwick and Fritts, 1994).

Gonzales-Rossia et al. (2006) applied pre-harvest GA_3 during flower induction to the Japanese plums ‘Black Diamond’ and ‘Black Gold’ and significantly reduced the number of flowers the next spring and with that the time to hand thin the trees by 45%. They concluded that the optimum GA_3 concentration to apply during flower induction is 50 mg·L^{-1} and resulted in a cost saving of up to 40%.

GA_3 and GA_{4+7} application to Japanese plums 'Laetitia' and 'Larry Ann' at a rate of 100 mg·L^{-1} resulted in no significant reduction in yield efficiency and fruit size, but fruit maturity was delayed and fruit firmness significantly increased in the season of application (De Villiers, 2014). GA_{4+7} was more effective than GA_3. In the following season, the GA_3 significantly increased the number of vegetative buds in 'Laetitia'. In 'Larry Ann', both GA treatments increased the number of vegetative buds while GA_3 significantly reduced the time needed to hand thin 'Larry Ann' but not 'Laetitia'. De Villiers (2014) also compared GA_3 and GA_{4+7} at various rates (100, 200 and 400 mg·L^{-1}) on 'African Rose™' and 'Pioneer' plums. The results regarding fruit quality and yield in the season of application were similar to 'Laetitia' and 'Larry Ann', except for a slight reduction in yield efficiency in 'African Rose™'. In the case of 'Pioneer', the GA_3 treatments significantly reduced the flower density and in the case of 'African Rose' both GA products significantly reduced the flower density. In 'African Rose', De Villiers (2014) noticed a linear decrease in the time required to hand thin trees as the rate of GA_3 increased. The same effect was observed for the number of fruitlets that required hand thinning.

Reducing flowers in the current season. Given the option, growers would much rather thin their trees in the current season when the flower density and quality of the trees are known (Byers et al., 1990). According to Greene et al. (2001), the only effective form of chemical thinning is the application of caustic thinners during peach bloom. This method is, however, often inconsistent and erratic (Greene et al., 2001). Therefore, growers are reluctant to apply these types of chemicals designed specifically to reduce fruit set before the set conditions are known (Greene et al., 2001).

Greene et al. (2001) applied the blossom thinners Wilthin® (monocarbamide dihydrogensulfate, Thinset (ammonium thiosulphate) and Endothal (dipotassium7-oxobicyclo (2,2,1) heptane-2,3,-dicarboxylate) at approximately 90-95% full bloom to 'Garnet Beauty' and 'Red Haven' peaches. The rates were 9.3 L·ha^{-1} and 14.0 L·ha^{-1} for Wilthin (including the surfactant Regulaid at 1.2 L·ha^{-1}), two rates of ammonium thiosulphate (ATS) of 37.4 L·ha^{-1} and 74.8 L·ha^{-1} and 1.5 L·ha^{-1} Endothal. Although all three blossom thinners reduced fruit set significantly, ATS was the only thinner that reduced the final fruit set after hand thinning

(Greene et al., 2001). Endothal and ATS both increased the weight and diameter of the fruit at harvest. However, Wilthin did not increase fruit size (Greene et al., 2001). Endothal increased the overall fruit size in 'Red Haven' but not 'Garnet Beauty'. ATS increased fruit size significantly in both cultivars. Greene et al. (2001) repeated this study with the same thinners and rates except for ATS which they decreased to 28.1 L·ha^{-1} and 37.4 L·ha^{-1}. Except for Wilthin, the treatments in general reduced fruit set. Endothal and ATS did not influence the fruit size significantly (Greene et al., 2001).

Greene et al. (2001) repeated the trials again, but applied the chemicals when 'Garnet Beauty' was at 60% full bloom and 'Red Haven' at 80% full bloom. The adjustment to the time of application was made because 'Garnet Beauty' did not respond as well too early thinning as 'Red Haven'. They also changed the rates of the chemicals applied to Wilthin at 14.0 L·ha^{-1} and 18.6 L·ha^{-1} (including Regulaid at 1.2 L·ha^{-1}), ATS at 37.4 L·ha^{-1} and 56.1 L·ha^{-1} and Endothal at 1.8 L·ha^{-1}. These treatments significantly reduced the initial set and the number of fruit that had to be removed during follow up hand thinning.

An advantage of using blossom thinners is that the damage being done to some of the flowers causes the reallocation of limited assimilates to the fewer healthy sinks (Southwick et al., 1996). Southwick et al. (1996) researched the surfactant Armothin® on Japanese plums in South Africa and found it active as blossom thinner. Armothin® was also effective on 'Loadel' cling peaches when applied at rates of 1, 3 and 5% at 80% full bloom, at full bloom and 3 DAFB. Armothin® application of 1% at all the phenological stages and 3% Armothin® at full bloom and just after full bloom had similar fruit set than that of the unsprayed control trees, but 3% Armothin® at 80% full bloom and 5% Armothin® at all the phenological stages did reduce the number of fruitlets significantly compared to the control. There was a linear reduction in fruit set as the rate of Armothin® increased within the bloom phenological stages. One of the disadvantages that resulted from using Armothin® was some damage to the trees. Typical symptoms include yellowing of leaves and dieback of young shoots. This, however, did not affect the fruit quality or yield when using 5% Armothin® on European plum (Meland, 2007) or 'Loadel' peach (Southwick et al., 1996).

Armothin® at 3% (v/v) at various phenological stages was compared to hand thinning at full bloom or 46 DAFB on 'Sunlite' nectarines by Coetzee and Theron (1999a). It did not reduce fruit set to the same extent as hand thinning at full bloom, but allowed for further spacing of fruit on shoots. It did reduce the initial fruit set compared to the fruit-thinned control that was thinned by hand 46 DAFB. The blossom stage at which Armothin® was applied had no effect on the initial fruit set. Having said that, the blossom stage, from bud swell to first pink, was a very broad stage and the first application during this stage (0 DAFB) reduced initial fruit set 30 DAFB compared with later Armothin® applications. Armothin® applications later in the flowering season enhanced fruit drop more than earlier applications.

Coetzee and Theron (1999a) found that early Armothin® application had a scorching effect on the reproductive buds, even when not open, which meant an immediate thinning effect. They also found that the efficacy of later Armothin® applications depended on the pollination state of the flower. When un-pollinated, the stigma of the blossom will be scorched, thus preventing fertilization. Costa et al. (1994) confirmed that if Armothin® is applied within 24 hours after pollination, but before fertilization, then the chemical will influence the pollen tube growth, but if the application took place after 24 hours of pollination it will not influence pollen tube growth. Coetzee and Theron (1999a) also noted that the late Armothin® applications had a delayed thinning effect. The early Armothin® applications reduced the yield significantly compared to the control treatments and also had a negative effect on fruit size when compared to the blossom-thinned control, but did not differ in fruit size compared to the fruit-thinned control. The earlier Armothin® applications increased fruit size significantly compared to the later Armothin® applications. Coetzee and Theron (1999b) concluded that Armothin® is a high risk chemical thinner when applied early in the flowering period to nectarines in areas that have a short flowering period as it can lead to over thinning and they suggested that in such areas Armothin® should therefore be applied later during flowering.

Coetzee and Theron (1999c) studied Armothin® application following application of the rest-breaking agents Armobreak® and potassium nitrate (KNO_3) to shorten the flowering period of 'Sunlite' nectarine. Armobreak® and KNO_3 were combined at a concentration of 2% (v/v) and 6%, respectively and then three different Armothin® concentrations, 1, 2 and 3% were applied at 80% full bloom. The rest-breaking treatment reduced the reproductive bud break percentage. Without the rest-breaking treatment, the number of fruit that had to be hand thinned decreased linearly with an increase in Armothin® concentration. When the rest-breaking treatment was included, no trend in Armothin® concentration was found. Armothin® applied at a concentration of 3% did have a significant thinning effect, but the thinning did not happen fast enough to achieve the desired fruit size effect (Coetzee and Theron, 1999c).

North and Booyse (2005) found that the closer the trees were to full bloom the more sensitive 'Alpine' nectarine blossoms were to Armothin® and the bigger the thinning effect. Armothin® was applied at 1.5% and 3% at three different stages, 11%, 17% and 42% full bloom (North and Booyse, 2005). On trees that were not thin by hand, the 1.5% application had no thinning effect when applied at 11% bloom, but it did thin when applied later. The 3% application did sufficiently thin when applied at 11% bloom and over thinned when applied at 17% and 42% full bloom. For all the treatments except 3% Armothin® at 11% full bloom, hand thinning was required. The 3% application thinned excessively when applied at the two later bloom stages.

Wilkins et al. (2004) evaluated the efficacy of the surfactant Tergitol-TMN-6 as a chemical thinner on 'Fire Prince' peaches. They also did a test comparing Tergitol-TMN-6 to TMN-10 (yleneoxyethanol). Both Tergitol-TMN-6 and TMN-10 were applied at full bloom and at petal fall at 20 $mL{\cdot}L^{-1}$ and 40 $mL{\cdot}L^{-1}$ and were compared to an unsprayed control. Both chemicals caused necrosis on flowers and reduced the number of fruitlets that had to be removed at commercial hand thinning by approximately 780 to 200 fruit per tree.

Tergitol-TMN-6 was applied to 'Fire Prince' peaches at rates of 10, 20 and 30 $mL{\cdot}L^{-1}$ (Wilkins et al., 2004). A linear decrease in the number of fruitlets that had to be thinned by hand was found as the rate of Tergitol-TMN-6 increased. The higher rates (20 and 30 $mL{\cdot}L^{-1}$) did cause some leaf yellowing. The authors concluded that rates of 20 and 30 $mL{\cdot}L^{-1}$ were too high due to the excessive thinning as some fruiting branches were without fruit. The higher rates did have the advantage of slightly bigger fruit than the 10 $mL{\cdot}L^{-1}$ rate and the control. The recommendation is therefore that Tergitol-TMN-6 should be applied at full bloom at a rate of 10 $mL{\cdot}L^{-1}$, as it provided effective thinning without any damage to the trees (Wilkins et al., 2004).

Tergitol-TMN-6 significantly reduced fruit set and increased fruit size in 'Empress' plums at 7.5 and 12.5 $ml{\cdot}L^{-1}$ (Fallahi et al., 2006). Tergitol-TMN-6 is effective over a wide range of phenological stages from full bloom to petal fall. This allows a longer window of application (Wilkins et al., 2004). The current recommendation for stone fruit is to apply Tergitol-TMN-6 at 75-80% full bloom at 7.5 - 12.5 $ml{\cdot}L^{-1}$ (Fallahi et al., 2006).

Reducing fruitlets in the current season. It is optimal for growers to thin fruitlets after bloom as they can first evaluate fruit set before any form of thinning is applied (Meland, 2007). 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 75 $\mu l \cdot L^{-1}$ combined with 10 $\mu l \cdot L^{-1}$ NAA applied 27 DAFB reduced fruit set significantly and advanced fruit maturity in European plum (Meland, 2007). The return bloom, however, was not improved by either treatment (Meland and Birken, 2010). Meland and Birken (2010) found effective thinning of 'Victoria' plums after application of Ethephon at 250, 375 and 500 $\mu l \cdot L^{-1}$ at full bloom and 125, 250 and 375 $\mu l \cdot L^{-1}$ at 10-12 mm fruitlet diameter. 6-BA is not effective as thinner on stone fruit (Schalk Reynolds, personal communication).

1-aminocyclopropane-1-carboxylic acid (ACC) is a new chemical thinner currently being evaluated in pome fruit. Schupp et al. (2012) found promising results when ACC was used to thin 'Golden Delicious' apple trees. The thinning effect increased linearly with increasing rate of ACC.

Conclusion

Hand thinning is the oldest and still the most widely used method to reduce the crop load in stone fruit. It is clear that thinning in stone fruit is important and with the continuing increase in labor costs (Pela, 2015) there is great need for an alternative to hand thinning. Mechanical thinning is an environmentally friendly alternative to hand thinning, but will only be more cost effective than hand thinning if the orchard is well adapted to the mechanical thinning device. The Darwin 300™, for example, can only be effective if the orchard floor is smooth and if the tree structure is adapted to the machine, e.g. hedge type training systems. There is a growing interest in the industry for a chemical thinner to thin fruitlets, rather than flowers, which will allow producers to decide whether to thin or not based on the current season's fruit set.

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.

Addicott, F.T. 1970. Plant hormones in the control of abscission. Biol. Rev. 45(4):485-524.

Bangerth, F. 2000. Abscission and thinning of young fruit and their regulation by plant hormones and bioregulators. Plant Growth Regul. 31(1):43–59. Available at: http://dx.doi.org/10.1023/A:1006398513703.

Baugher, 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(4):755-761.

Baugher, T.A., K. Ellis, J. Remcheck, K. Lesser, J. Schupp, E. Winzeler and K. Reichard. 2010. Mechanical string thinner reduces crop load at variable stages of bloom development of peach and nectarine trees. HortScience 45(9):1327–1331.

Berlage, A. and R. Langmo. 1982. Machine-vs hand-thinning of peaches. Transactions of the Amer. Soc. of Agri. Engineers. 538-543.

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

Byers, R., D. Carbaugh, and C. Presley. 1990. The influence of bloom thinning and GA3 sprays on flower bud numbers and distribution in peach trees. J. Hortic. Sci. 65(2):143-150.

Coetzee, J. and K. Theron. 1999a. Efficacy of Armothin® as a chemical thinner applied during different flowering stages of ‘Sunlite’ nectarines. J. SA. Soc. Hort. Sci. 9(1):8-12.

Coetzee, J. and K. Theron. 1999b. The effect of Ralex on fruit firmness and storage ability in the season of application and on bud density, yield and fruit size in the season following application in 'Sunlite' nectarines. J. SA. Soc. Hort. Sci. 9(1):13-17.

Coetzee, J. and K. Theron. 1999c. The effect of the rest-breaking agent, Armobreak in combination with potassium nitrate, on the efficacy of Armothin® as a chemical blossom thinner for 'Sunlite' nectarines. J. SA. Soc. Hort. Sci. 9(1):18-20.

Costa, G., G. Vizzotto, C. Malossini, and A. Ramina. 1994. Biological activity of a new chemical agent for peach flower thinning. Plant Bioregulators in Hort. 394:123-128.

Costa, G. and G. Vizzotto. 2000. Fruit thinning of peach trees. Plant Growth Regul. 31:113–119.

Damerow, L., and M.M. Blanke. 2009. A novel device for precise and selective thinning in fruit crops to improve fruit quality. Acta Hort. 824:275-280.

Day, K.R. and T.M. DeJong. 1998. Improving fruit size: Thinning and girdling nectarines, peaches, and plums. The Compact Fruit Tree. 32(2):1–6.

DeJong, T. and Y.L. Grossman. 1994. A supply and demand approach to modeling annual reproductive and vegetative growth of deciduous fruit trees. HortScience 29(12):1435–1442.

De Villiers, M.H.J. 2014. Mechanical and chemical thinning of stone fruit. MScAgric thesis, Stellenbosch University.

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(5):1243–1248.

Gonzalez-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.

Greene, D.W., K.I. Hauschild, and J. Krupa. 2001. Effect of blossom thinners on fruit set and fruit size of peaches. HortTechnology 11(2):179-183.

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(1):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.

North, M. and M. Booyse. 2005. Effect of blossom stage of ‘Alpine’ nectarine on efficacy of chemical thinning using Armothin®. S. Afr. J. Plant and Soil 22(3):154-157.

Pela, M. Department of Labour. 2015/2016. Labour Minister Oliphant increases farmworkers minimum wage by 7,7 percent in 2015/16. <http://www.labour.gov.za/DOL/media-desk/media-statements/2015/labour-minister-oliphant-increases-farmworkers-minimum-wage-by-7-7-percent-in-2015-16/?searchterm=farmworkers.>

Powell, A., B. Hancock, E. Puls Jr., S. Helmers, and M. Brown Jr. 1975. Utilizing mechanical fruit thinning in commercial peach orchards. HortScience 10(2):142.

Rasori, A., B. Ruperti, C. Bonghi, P. Tonutti, and A. Ramina. 2002. Characterization of two putative ethylene receptor genes expressed during peach fruit development and abscission. J. Exp. Bot. 53(379):2333-2339.

Reighard, G. and R. Byers. 2009. Peach thinning. Department of Horticulture. Clemson University. Clemson, SC, retrieved November, 22.

Schupp, J., T.A. Baugher, S. Miller, R. Harsh, and K. Lesser. 2008. Mechanical thinning of peach and apple trees reduces labor input and increases fruit size. HortTechnology 18(4):660-670.

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(9):1308-1311.

Southwick, S.M., and K. Glozer. 2000. Reducing flowering with gibberellins to increase fruit size in stone fruit trees: applications and implications in fruit production. HortTechnology 10(4):744-751.

Southwick, S.M., and R. Fritts, Jr. 1994. Commercial chemical thinning of stone fruit in California by gibberellins to reduce flowering. Plant Bioregulators in Hort. 394:135-148.

Southwick, S.M., J.T. Yeager, and Z. Hong. 1995. Flowering and fruiting in 'Patterson' apricot (*Prunus armeniaca*) in response to postharvest application of gibberellic acid. Sci. Hort. 60(3-4):267-277.

Southwick, S.M., K.G. Weis, and J.T. Yeager. 1996. Bloom thinning 'Loadel' cling peach with a surfactant. J. Am. Soc. Hort. Sci. 121(2):334-338.

Stover, E. 2000. Relationship of flowering intensity and cropping in fruit species. HortTechnology 10(4):729-732.

Webster, A., and J. Spencer. 2000. Fruit thinning plums and apricots. Plant Growth Regul. 31(1-2):101-112.

Weinberger, J. 1941. Studies on time of peach thinning from blossoming to maturity. Proc. Amer. Soc. Hort. Sci. 38:137–140

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 Regul. 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(7):1611–1613.

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-l-carboxylic acid (ACC) and ACC synthase. Plant Cell Physiol. 22(3):369–379.

PAPER 1: The Efficacy of Chemical and Mechanical Thinning Strategies for Japanese Plums (Prunus salacina Lindl.)

Additional index words. 1-aminocyclopropane-1-carboxylic acid (ACC), 6-benzyladenine (6-BA), Darwin 300™, thinning, yield, fruit quality.

***Abstract*. Japanese plum production is an important component of the South African deciduous fruit industry. Thinning is an important practice in plum production and there is a huge need for new thinning strategies. The purpose of this study was to evaluate new chemical thinning strategies on 'Laetitia', 'Fortune' and 'African Rose™'. The chemicals evaluated were 1-aminocyclopropane-1-carboxylic acid (ACC) and 6-benzyladenine (6-BA). These were also combined with mechanical thinning utilizing the Darwin 300™ or hand thinning during bloom in one season on 'African Rose™'. All the foliar applications were made when the average fruitlet size was 8-10 mm. 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 efficiency and a quadratic response in fruit size as the ACC rate increased. The combination treatment of ACC and the Darwin 300™ used in the 'African Rose™' trial thinned more aggressively, improved fruit size and shifted harvest distribution earlier. The yield efficiency 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-1 and for 'Laetitia' 400 µl.L-1. For 'Fortune' a recommended rate cannot be made at this stage, thus further trials should be conducted. No leaf drop/phytotoxicity was recorded in any trials except in the pilot non-statistical trial when ACC was applied at noon with temperatures above 30 ^{o}C. No broken stones were observed in any trial.**

South Africa is an important role-player in the international deciduous fruit market and new innovative ideas are needed to remain competitive. In the past, labor cost in South Africa was relatively low compared to other fruit producing countries, but recently labor cost has increased and will keep on escalating (Pela, 2015). Thinning of Japanese plum (*Prunus salicina* Lindl.) is highly labor intensive. Developing new ways to thin flowers or fruit might reduce cost substantially.

Natural fruit abscission in most Japanese plums is usually not sufficient to reduce crop load to the correct commercial level. A change in the abscission zone at the pedicel base of fruit is mainly responsible for flower or fruitlet drop in deciduous fruit trees. Ethylene stimulates abscission, but if sufficient auxin is translocated from the fruit across the abscission zone, fruit drop will not occur (Wertheim, 1997). The reason why young fruitlets drop is the presence of slightly older fruit (earlier fruit set) exerting premigenic dominance by exporting more indole-3-acetic-acid (IAA). The reason for dominance could also be higher seed numbers in pome fruit (Bangerth, 2000). A strong bourse shoot in pome fruit could also be exporting a strong IAA signal resulting in less dominant fruitlets to drop (Bangerth, 2000). In plums, flowers also occur in clusters, but usually only one embryo develops per fruit and bourse shoots are not present, but new shoots do develop in close proximity to fruitlets.

Annual cropping is very important and this can be achieved through thinning. By reducing the number of fruit on the tree, the remaining fruit will develop to the optimal size and return bloom the next season will be adequate for a good crop load (Njoroge and Reighard, 2008). There are various times and ways of thinning, for example pre-bloom, at full bloom and post-bloom and the cheapest and earliest method of thinning is pruning (Njoroge and Reighard, 2008). However, even when the 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). Also, thinning must be done each year, because of the advantages it has on flower number, fruit size, fruit quality, fruit-to-shoot ratio and in preventing alternate bearing (Costa et al., 1983).

One chemical thinning approach for plums is to use gibberellins, e.g. gibberellic acid (GA_3), but results are inconsistent. GA_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_3 must be applied when flower-bud differentiation can be affected (Costa and Vizzotto, 2000). The main reason why GA_3 sprays are not used as a chemical thinner is because "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).

Gonzales-Rossia et al. (2006) applied pre-harvest GA_3 at 50 mg·L^{-1} and 75 mg·L^{-1} during flower induction to the plum cultivars, Black Diamond and Black Gold. These GA_3 sprays reduced the number of flowers the next spring significantly, more so on vigorous shoots with 50 mg·L^{-1} being the most effective since it reduced the cost of thinning by 45-47% and increased fruit size by 7-33% (González-Rossia et al., 2006). De Villiers (2014) was able to reduce return bloom and the required time to hand thin 'Larry Ann' trees at commercial hand thinning with rates of 100 mg·L^{-1} GA_3 or GA_{4+7}.

A preferred alternative approach is using blossom thinners that scorch 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 ml·L^{-1} and 12.5 ml·L^{-1}) (Fallahi et al., 2006). Tergitol-TMN-6 is effective over a wide range of phenological stages from full bloom to petal fall. This allows a longer window of application (Wilkins et al., 2004). The current recommendation for stone fruit is to apply Tergitol-TMN-6 at 75-80% full bloom at 7.5 - 12.5 ml·L^{-1} (Fallahi et al., 2006).

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^{-1} applied to 'Victoria' plums at full bloom did not reduce fruit set while 75 µl·L^{-1} Ethephon combined with 10 µl·L^{-1} NAA applied 27 days after full bloom (DAFB) did reduce fruit set significantly. Both the 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 1-aminocyclopropane-1-carboxylic acid (ACC) (Schupp et al., 2012.). Adams and Yang (1979) found that applied 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 (Theron et al., 2015; Miller et al., 2011) Miller et al. (2011) evaluated the Darwin™ string thinner on large peach trees trained to a perpendicular-V system and found that it effectively thinned peach flowers in the upper canopy at 80% full bloom. However, it did not have any effect in the lower canopy or scaffold limbs of the tree (Miller et al., 2011). 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., 2001; 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).

The purpose of this study was to evaluate the efficacy of new chemical thinning strategies, 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. The chemical thinning treatments were also combined with mechanical thinning utilizing 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 two trials were conducted on Japanese plums. One was on the cultivar African Rose™ and one pilot, non-statistical trial on Laetitia to establish the potential efficacy of ACC on

Laetitia. Both trials were conducted on the farm Sandrivier (33°35’58.0” S, 18°55’40.1” E) near Wellington in the Western Cape, South Africa. The mature ‘African Rose™’ trees, on Marianna rootstocks, 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 the cross pollinator. The planting system used for the mature ‘Laetitia’ orchard planted in 1996 was the same as for ‘African Rose™’ with 10% ‘Songold’ trees as the cross pollinator.

Experimental layout for the 2013/2014 season. In ‘African Rose™’ two products were evaluated, viz., ACC (VBC 30160; Philagro SA Pty (Ltd.), Somerset West, South Africa) and 6-BA (MaxCel™; Philagro SA Pty (Ltd.), Somerset West, South Africa. Seven treatments were used as summarized in Table 1. A randomized complete block design with eight single tree replications was used. All the foliar applications were made using a motorized knapsack sprayer (STIHL, Pietermaritzburg, South Africa) when the average fruitlet size was 7-10 mm. Each tree was sprayed for 30 seconds, thus applying approximately 1L of solution per tree under slow drying conditions when the temperature was between 10 to 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 for all the trials were favorable for at least five days with temperatures above 18 °C. Dates of application, hand thinning and harvests are summarized in Table 2.

Pilot, non-statistical trial. Treatments were applied as summarized in Table 1. Each treatment was applied to three consecutive trees of which the middle tree served for data recording. All foliar applications were applied using a knapsack sprayer when the average fruitlet diameter was between 8 -12 mm as described above. Applications were made around noon when temperatures were above 30 °C on 26 October 2013.

Plant and site description for the 2014/2015 season. Trials were conducted on the Japanese plum cultivars African Rose™, Fortune and Laetitia. Mature ‘Fortune’ and ‘African Rose™’ trees on the farm Sandrivier (33°35’58.0” S, 18°55’40.1” E) near Wellington in the Western Cape, South Africa were used. A ‘Laetitia’ orchard on Fransmanskraal (33°35’34.7” S, 18°49’06.4” E), Devon Valley, near Stellenbosch was selected. The trial on ‘African Rose™’ was in the same orchard as in the previous season, but on different trees. The ‘Fortune’ on Marianna rootstocks were planted in 2005 at 4.5 m x 0.75 m and trained to a V-hedge-system. The cross pollinator in this orchard was 10% ‘Angeleno’. The ‘Laetitia’ trees on Marianna rootstocks were relatively young, planted in 2011 at a spacing of 3.25 m x 1.5 m and trained to a Palmette-system. The cross pollinator was ‘Sunbreeze’ and planted every alternate row. All applications were done under slow drying conditions as described for the previous season.

Experimental layout for the 2014/2015 season. The ‘African Rose™’ trial consisted of 10 treatments in a randomized complete block design with 10 replicates as summarized in Table 3. For the mechanical thinning treatments each replicate consisted of five trees with the middle tree used to record data. For this trial the Darwin 300™ was utilized at 160 rpm at a tractor speed of 4.8 $km \cdot h^{-1}$. The flower thinning treatment was done by removing every second flower cluster, thus removing 50% of the flowers. Dates of application, hand thinning and harvests are summarized in Table 4. The ‘Fortune’ trial consisted of six treatments in a randomized complete block design with 10 replicates as summarized in Table 5. Dates of application, hand thinning and harvests are summarized in Table 6. The ‘Laetitia’ trial also consisted of six treatments in a randomized complete block design with 9 replicates as summarized in Table 5. Dates of application, hand thinning and harvests are summarized in Table 6.

All the foliar applications were made using a motorized knapsack sprayer, when the average fruitlet size was 8-10 mm as described for the previous season. In all three trials, at least one tree was left between the treated trees that served as a buffer tree to prevent drift effects. A buffer row was left as well where more than one row was used for a trial. The conditions following the applications for all the trials were favorable for at least five days with temperatures above 18 ^{o}C.

Data collection. In all trials the same data were recorded except in the pilot ‘Laetitia’ trial, where no harvest data was collected. After the application of the treatments, a period of at least two weeks was allowed for fruitlets to drop. Hand thinning was done according to standard commercial practices. 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 and after harvest the trunk cross sectional area measured to determine total yield efficiency as kg fruit per trunk cross sectional area ($kg \cdot cm^{-2}$). 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 GÜSS texture analyzer (Guss electronic model GS 20, Strand, South Africa) while broken stones was recorded as either present or not. For the pilot trial only the number of fruitlets thinned by hand was recorded.

Statistical analysis. The data were analyzed using SAS Enterprise guide 5.1 (SAS Institute Inc., Cary, North Carolina, USA) using the linear model procedure and the pairwise t-test to determine the Least Significant Difference (LSD) when the F-statistic indicated significance at $P<0.05$. Single degree of freedom, orthogonal, polynomial contrasts were fitted where applicable.

Results

Results for the 2013/2014 season: 'African Rose™'. The highest rate of ACC (500 $\mu l \cdot L^{-1}$) significantly reduced the number of fruitlets that had to be thinned by hand during commercial hand thinning compared to the control (Table 7). The increase in ACC rate resulted in a linear decrease in the number of fruitlets that needed hand thinning. 6-BA did not result in significant thinning, not even at the high rate. The addition of 6-BA to the high rate of ACC did not affect the thinning efficacy (Table 7) and no leaf drop/phytotoxicity was observed in this trial. The average weight of a thinned fruitlet increased quadratically up to the ACC 300 $\mu l \cdot L^{-1}$ treatment (Table 7). The weight of the thinned fruitlets of the two 6-BA applications, ACC 150 $\mu l \cdot L^{-1}$, as well as the combination treatment, did not differ significantly from the untreated control. The time it would take to complete the follow-up hand thinning per tree was significantly reduced by the highest concentration ACC and the combination treatment compared to the control. There was a linear decrease in time required to thin with the increase in ACC rate (Table 7).

No significant differences were found in the total yield, total yield efficiency per tree or yield efficiency at either of the two harvest dates (Table 8). However, a linear increase in total yield efficiency was found with increasing ACC rate. The treatments did not significantly alter harvest distribution or have an effect on the average overall fruit weight at harvest (Table 9). There was no significant difference in the average fruit size (weight, diameter or length) at either harvest date, however the average fruit diameter for the ACC treated trees were significantly higher than that of the 6-BA treated trees (Table 10-11). Fruit firmness at the first harvest date was on average significantly higher for fruit from 6-BA compared to ACC treated trees (Table 12) while at the second harvest fruit from control trees on average were significantly firmer than fruit from all other trees (Table 12).

'Laetitia'. In this pilot trial it appeared as if the ACC reduced the hand thinning requirement linearly with higher rates (Table 13). Severe leaf drop was observed with increasing ACC rate in this trial.

Results from the 2014/2015 season: 'African Rose™'. Both the Darwin 300™ and hand flower thinning treatment at full bloom significantly reduced the number of fruitlets that had to be thinned by hand during commercial hand thinning compared to the control (Table 14). All ACC applications also significantly reduced the number of fruitlets that had to be thinned by hand during commercial hand thinning compared to the control (Table 14). 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 even more when compared to the ACC treatments (p=0028) (Table 14). 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 14). No leaf drop/phytotoxicity was observed in this trial.

All the treatments, except 6-BA, significantly increased the average weight of the thinned fruitlets significantly compared to the control (Table 14). The average weight of the thinned fruitlets for the ACC and Darwin 300™ combination treatments were significantly higher than that of the same ACC rates on their own.

Only the highest rate of ACC (800 $\mu l \cdot L^{-1}$) on its own and in combination with the Darwin 300™ reduced the total yield per tree compared to the control (Table 15). There was a quadratic trend in total yield per tree with increasing ACC rate with the highest rate reducing yield significantly. There was a significant effect on the yield efficiency for the third harvest date with a linear decrease in the yield efficiency with increasing ACC rate. The same occurred with total yield efficiency with the highest rate of ACC being the only one significantly lower than the control (Table 15). On average all treatments altered the harvest distribution compared to the control. 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 16). All the treatments increased the average fruit weight except for 6-BA and again the average fruit weight increased quadratically with the ACC rate, with ACC 600 µl·L^{-1} having the highest fruit weight of the ACC treatments (Table 16). Also, the average weight of the two higher ACC rates (600 µl·L^{-1} and 800 µl·L^{-1}) and two ACC and Darwin 300™ combination treatments had significantly larger fruit compared to the rest of the treatments.

In general, average fruit size (weight, diameter and length) for both the first and second harvest was increased by all treatments (Table 17-18). The average fruit size at first harvest increased quadratically with the rate of ACC application. The average fruit weight of the ACC treatments at the first harvest was significantly higher than that of the control. Both the average fruit diameter and –length of both combination treatments between the Darwin 300™ and ACC were significantly higher than the control. Also there was a linear increase in fruit length during the second harvest as the ACC rate increased (Table 18). During harvest three there was a linear increase in the average fruit diameter as the ACC rate increased (Table 19). There was a significant effect on the average fruit shape (ratio of diameter to length) during the first and third harvest, but not of any horticultural importance (Table 17-19). On average fruit firmness for the control was higher during harvest one. The same was observed for the two ACC and Darwin 300™ treatments compared to the ACC treatments. During harvest two there was a significant quadratic change in fruit firmness with ACC rate with the high rate resulting in firmer fruit than the two lower ACC rates and the ACC 800 µl·L^{-1} in combination with the Darwin 300™ treatment (Table 20). There was a significant increase in the incidence of broken stones during the first harvest for all the combination treatments and the flower thinning treatment. The ACC and Darwin 300™ combination treatments had significantly more broken stones than the ACC 800 µl·L^{-1} treatment, but broken stone levels were very low (Table 21).

'Fortune'. The two higher rates of ACC significantly reduced the number of fruitlets that had to be thinned by hand during commercial hand thinning compared to the control (Table 22). The increase in ACC rate resulted in a linear decrease in the number of fruitlets that required hand thinning. 6-BA did not result in significant thinning, but increased the hand thinning required, thus increased fruit set. The addition of 6-BA to the high rate of ACC did have an additional thinning effect. No leaf drop/phytotoxicity was observed in this trial.

These treatments had no significant effect on the average weight of the hand thinned fruitlets (Table 22).

The two higher ACC rates and the combination treatment with 6-BA reduced the total yield significantly when compared to the control and the increase in ACC rate resulted in a quadratic decrease in the total yield (Table 23). The same effect was observed in yield efficiency of the second harvest and the total yield efficiency while no significant differences were observed in yield efficiency at the first harvest date (Table 23). The harvest distribution was not altered by any treatment, but there was a trend for advancement of harvest with the increase of ACC rate (p=0.051) (Table 24). The ACC 600 $\mu l \cdot L^{-1}$ and ACC and 6-BA combination treatment increased the average overall fruit weight when compared to the control (Table 24). The 6-BA and two lower ACC rates did not have any significant effect on the average fruit weight (Table 24). No differences were found in average fruit size at the first harvest date, even though ACC 600 $\mu l \cdot L^{-1}$ and the 6-BA in combination with ACC increased fruit diameter. 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 size as the ACC rates increased (Table 26). There was a significant effect on the average fruit shape (ration of diameter to length) for both harvests, but not of any horticultural importance (Table 25-26). These treatments had no significant effect on fruit firmness or the occurrence of broken stones (Table 27-28).

'Laetitia'. The two higher ACC rates significantly reduced the number of fruitlets that had to be thinned by hand during commercial hand thinning compared to the control (Table 29). The increase in ACC rate resulted in a linear decrease in the hand thinning requirement. 6-BA application did not result in significant thinning. The ACC and 6-BA combination treatment had an even bigger thinning effect and thinned significantly more aggressively than the ACC alone. All treatments reduced the average weight of the thinned fruitlets significantly when compared to the control (Table 29). No leaf drop/phytotoxicity was observed in this trial.

The highest ACC rate and the combination treatment reduced the total yield significantly and the combination treatment reduced the total yield efficiency significantly in comparison to the control (Table 30). The increase in ACC rate resulted in a linear decrease in the total yield and total yield efficiency (Table 30). The two higher ACC rates and the combination treatment increased average fruit size (weight, diameter and length) significantly compared to the control with a linear increase in fruit size as the ACC application rate increased (Table 31). There was a significant effect on the average fruit shape in this trial, but not of any horticultural importance (Table 31). Both the 6-BA and the combination treatment between ACC and 6-BA reduced the average fruit firmness significantly compared to the control (Table 31). No broken stones were observed.

Discussion

'African Rose™'. The highest ACC rate of 500 µl·L^{-1}, 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 were thinned and the time required to thin these trees during commercial hand thinning. Exogenously applied Ethephon increases ethylene levels in plants (Wertheim, 1997) which stimulates fruit abscission (Wertheim, 2000) and therefore a similar response to ACC, a precursor of ethelyne is expected. Meland and Birken (2010) found effective thinning of 'Victoria' plums after application of Ethephon at 250, 375 and 500 µl·L^{-1} at full bloom and 125, 250 and 375 µl·L^{-1} at 10-12 mm fruitlet diameter. Schupp et al. (2012) found promising results when ACC was used to thin 'Golden Delicious' apple trees. The thinning effect increased linearly with increasing rate of ACC (Schupp et al., 2012). In the subsequent season (2014/15) we applied higher rates of ACC (600 and 800 µl·L^{-1}), but still a large number of fruit had to be thinned by hand. 'African Rose™' is self-fertile (Culdevco, 2009) and therefore sets excessive fruit. During both seasons the most effective ACC treatments showed the benefit of early thinning in that the average fruit size of the hand thinned fruitlets was already larger at the time of hand thinning. With the settings chosen for the Darwin 300™, it was expected that utilizing the machine at full bloom, it would have a similar thinning effect as the 50% hand flower thinning treatment, and both these treatments resulted in larger fruitlets at commercial hand thinning when compared to the control. De Villiers (2014) also evaluated the Darwin 300™ on 'African Rose™' plums with various rotor speeds, 220, 250 and 280 rpm and all treatments significantly reduced the required hand thinning time compared to the control. The benefit of early flower 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 to 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 size (weight, diameter and length) or fruit firmness were found with any ACC treatments. Therefore the thinning obtained with the 500 $\mu l \cdot L^{-1}$ 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 $\mu l \cdot L^{-1}$ over thinning and resulting in a significantly lower yield than the control. The yield and yield efficiency of the 600 $\mu l \cdot L^{-1}$ ACC did not differ significantly from the control, thus indicating this as the recommended ACC rate for 'African Rose™'. The combination treatment of ACC 800 $\mu l \cdot L^{-1}$ and Darwin 300™ also significantly reduced the yield efficiency compared to the control. However, the yield of the combination treatment of the Darwin 300™ and ACC 600 $\mu l \cdot L^{-1}$ did not differ from the control even though the thinning effect of the combination treatment was significantly higher than the treatments on their own. Even though the yield of this combination treatment was significantly lower than the yield of the ACC 600 $\mu l \cdot L^{-1}$ treatment alone, the yield efficiency did not differ from each other. The Darwin 300™ on its own and 50% hand flower thinning during bloom did not significantly reduce yield efficiency compared to the control. De Villiers (2014) found similar results for total yield efficiency when using the Darwin 300™. With the increase in ACC rates in the 2014/2015 season a linear decrease in yield efficiency was observed as the rate of ACC increased which should make it possible to find the correct rate of ACC depending on the yield efficiency 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 indicating that fruit maturity was advanced by the heavy thinning treatments resulting in advanced harvesting. Wünsche et al. (2000) reported that fruit maturity of 'Braeburn'/M.26 apples was advanced on low-cropping trees.

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 to the fruit of un-thinned trees and this is a well-known response to fruit thinning (Costa et al., 1983). The Darwin 300™ treatment increased the average fruit weight significantly compared to 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^{-1} and these two ACC rates alone significantly increase fruit size compared to the untreated control, but also more so than the flower thinning treatments alone and the lowest ACC (400 µl·L^{-1}) rate. The quadratic effect in fruit size that was observed for the ACC treated trees indicated that the 600 µl·L^{-1} 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™’.

‘Laetitia’. From the pilot trial with ACC on ‘Laetitia’ in 2013/2014, some promising thinning responses were observed, 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 mid-day 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 and the 6-BA treatment alone did not have any thinning effect when compared to the control, but the added 6-BA in combination with the high ACC rate had an even bigger thinning effect. Because this ‘Laetitia’ orchard was relatively young and still growing vigorously, the 6-BA could have further stimulated shoot growth when added to the ACC causing even more competition between the shoots and fruitlets resulting in this severe thinning effect of the fruitlets. 6-BA may have stimulated the growth of lateral side shoots (Green and Autio, 1992; Elfving and Cline, 1993) and the IAA transport out of all the newly released lateral buds may have correlatively inhibited 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.

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 hand thinning was reduced by 44% without a negative effect on yield. Even though the highest ACC rate (600 µl·L^{-1}) did reduce the number of fruitlets that still needed to be thinned by hand more than the 400 µl·L^{-1} ACC application, the total yield for the high rate was significantly lower compared to the control. The severe thinning effect achieved with the combination treatment (ACC and 6-BA) did lead to over thinning due to the significantly lower yield than that of the control and the highest ACC rate application. The two higher ACC concentrations (400 µl·L^{-1} and 600 µl·L^{-1}) had a positive effect on fruit size (weight, diameter and length) with the significant and linear increase in the average diameter and average fruit length as the ACC rate increased. 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).

'Fortune'. The two higher ACC rates successfully reduced hand fruit thinning as did the combination treatment between ACC and 6-BA. However, in this trial there was no added benefit regarding the average weight of the individual fruitlets thinned by hand. It appears though that these treatments over thinned as the total yield and total yield efficiency of these treatments were significantly lower compared to 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 combined 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 in order to achieve fruit of adequate size, regulation of crop load is essential (Day and DeJong, 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 in 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.

Conclusion

The thinning effects we obtained with ACC on Japanese plums were promising. 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}, while 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. The Darwin 300™ shows a lot of promise. The thinning required for the Darwin 300™ was approximately 50% less than that of the control without influencing yield and with a positive effect on fruit size. Another conclusion is that 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 (abstr.).

Baugher, T.A., J.R. Schupp, K.M. Lesser, and K. Hess-Reichard. 2009. Horizontal string blossom thinner reduces labour input and increases fruit size in peach trees trained to open-center systems. HortTechnology 19(4):755–761.

Baugher, T.A., K. Ellis, J. Remcheck, K. Lesser, J. Schupp, E. Winzeler and K. Reichard. 2010. Mechanical string thinner reduces crop load at variable stages of bloom development of peach and nectarine trees. HortScience 45(9):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. Available at: http://dx.doi.org/10.1023/A:1006398513703.

Byers, R.E. and D.H. Carbaugh. 1991. Effect of chemical thinning sprays on apple fruit set. HortTechnology 1(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. of Hort. Sci. 65(2):143–150.

Costa, G., C. Giulivo, and A. Ramina. 1983. Effects of the different flower/vegetative buds 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 Regul. 31:113–119.

Culdevco. http://www.culdevco.co.za/images/stories/STONE/AFRICANROSEARCPR-4-Releasedin2009.pdf

Day, K.R. and T.M. DeJong. 1998. Improving fruit size: Thinning and girdling nectarines, peaches, and plums. The Compact Fruit Tree 32(2):1–6.

DeJong, T. and Y.L. Grossman. 1994. A supply and demand approach to modeling annual reproductive and vegetative growth of deciduous fruit trees. HortScience 29(12):1435–1442.

De Villiers, M.H.J. 2014. Mechanical and chemical thinning of stone fruit. MScAgric thesis, Stellenbosch University.

Elfving D.C. and RA 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(5):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. Autio, 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. DeJong. 1995. Maximum fruit growth potential and seasonal patterns of resource dynamics during peach growth. Ann. Bot-London 75:553–560.

Martín, 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(1):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. DeJong. 1993. Source-and sink-limited growth periods of developing peach fruits indicated by relative growth rate analysis. J. Amer. Soc. Hort. Sci. 118(6):820–824.

Pela, M. Department of Labour. 2015/2016. Labour Minister Oliphant increases farmworkers minimum wage by 7.7 percent in 2015/16. <http://www.labour.gov.za/DOL/media-desk/media-statements/2015/labour-minister-oliphant-increases-farmworkers-minimum-wage-by-7-7-percent-in-2015-16/?searchterm=farmworkers.>

Reighard, G. and R. Byers. 2009. Peach thinning. Department of Horticulture. Clemson University. Clemson, SC, retrieved November, 22.

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(4):660–670.

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(9):1308-1311.

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(2):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 Regul. 31:85-100 (abstr.).

Wilkins, B.S., R.C. Ebel, W.A. Dozier, J. Pitts and R. Boozer. 2004. Tergitol TMN-6 for thinning peach blossoms. HortScience 39(7):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(1):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-l-carboxylic acid (ACC) and ACC synthase. Plant Cell Physiol. 22(3):369–379 (abstr.).

Table 1. Treatment specifications for trials done with 6-benzyladenine (BA) and 1-aminocyclopropane carboxylic acid (ACC) on 'African Rose™' and 'Laetitia' plums in the season of 2013/2014.

African Rose™	Laetitia
Untreated control	Untreated control
6-benzyladenine (6-BA) (100 µl·L^{-1}) at 8-10 mm fruit diameter*	ACC (300 µl·L^{-1}) at 8-10 mm fruit diameter*
6-benzyladenine (6-BA) (300 µl·L^{-1}) at 8-10 mm fruit diameter*	ACC (400 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (150 µl·L^{-1}) at 8-10 mm fruit diameter*	ACC (500 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (300 µl·L^{-1}) at 8-10 mm fruit diameter*	
ACC (500 µl·L^{-1}) at 8-10 mm fruit diameter*	
6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1}) at 8-10 mm fruit diameter*	

* Actual average fruitlet diameter at application was 7-10 mm for both cultivars.

Table 2. Summary of the dates of treatment application, follow up hand thinning of fruitlets and harvest for 'African Rose™' in the season of 2013/2014.

Phenological stage	African Rose™
	6-BA and ACC
Application	11 Sept. 2013
Follow up hand thinning of fruitlets	1 Oct. 2013
Harvest	18 Nov. 2013

Table 3. Treatment specifications for trials done with 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and the Darwin mechanical string thinner on 'African Rose™' plums in the season of 2014/2015.

Treatments
Untreated control
Darwin 300™** at full bloom
Flower thinning
6-benzyladenine (6-BA) (100 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (400 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (600 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (800 µl·L^{-1}) at 8-10 mm fruit diameter*
6-BA (100 µl·L^{-1}) + ACC (800 µl·L^{-1}) at 8-10 mm fruit diameter*
Darwin at full bloom + ACC (600 µl·L^{-1}) at 8-10 mm fruit diameter*
Darwin at full bloom + ACC (800 µl·L^{-1}) at 8-10 mm fruit diameter*

* Actual average fruitlet diameter at application was 7.2 mm.

**Darwin 300™ at 160 rpm at a tractor speed of 4.8 km·h^{-1}.

Table 4. Summary of the dates of treatment application, follow up hand thinning of fruitlets and harvest for 'African Rose™' in the season of 2014/2015.

Phenological stage	6-BA, ACC, hand thinning and mechanical thinning
	African Rose™
Mechanical thinning with Darwin	12 Aug. 2014
Flower thinning	12 Aug. 2014
Chemical application	3 Sept. 2014
Follow-up hand thinning of fruitlets	16 Sept. 2014
Harvest dates	10, 14, 17 Oct. 2014

Table 5. Treatment specifications for trials done with 6-benzyladenine (BA) and 1-aminocyclopropane carboxylic acid (ACC) on cultivars Fortune and Laetitia in the season of 2014/2015.

Treatments
Untreated control
6-BA (100 $\mu l \cdot L^{-1}$) at 8-10 mm fruit diameter*
ACC (200 $\mu l \cdot L^{-1}$) at 8-10 mm fruit diameter*
ACC (400 $\mu l \cdot L^{-1}$) at 8-10 mm fruit diameter*
ACC (600 $\mu l \cdot L^{-1}$) at 8-10 mm fruit diameter*
6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$) at 8-10 mm fruit diameter*

* Actual average fruitlet diameter at application was 9.1 mm for 'Fortune' and 9.25 mm for 'Laetitia'.

Table 6. Summary of the dates of treatment application, follow up hand thinning of fruitlets and harvest dates for cultivars Fortune and Laetitia in the season of 2014/2015.

Phenological stage	Fortune	Laetitia
Chemical application	1 Oct. 2014	3 Oct. 2014
Follow-up hand thinning of fruitlets	15 Oct. 2014	17 Oct. 2014
Harvest dates	22, 26 Dec. 2014	14 Jan. 2015

Table 7. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit set and thinning required in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment	Average number of fruitlets thinned by hand		Average weight of hand thinned fruitlets (g)		Time to thin ($min \cdot tree^{-1}$)	
Control	1799	a	2.3	cd	27.7	a
6-BA 100	1868	a	2.1	d	25.3	ab
6-BA 300	1747	ab	2.2	d	24.7	ab
ACC 150	1852	a	2.3	cd	26.2	ab
ACC 300	1572	abc	2.6	a	24.7	ab
ACC 500	1424	c	2.6	ab	20.7	c
6-BA + ACC*	1490	bc	2.4	bc	23.6	bc
Significance level	*0.0177*		*<0.0001*		*0.0241*	
LSD 5%	*302*		*0.20*		*228.41*	
BA vs. ACC	*0.0537*		*<0.0001*		*0.3641*	
ACC Linear	*0.0075*		*0.0286*		*0.0044*	
ACC Quadratic	*0.4596*		*0.0153*		*0.6131*	
Control vs. Rest	*0.2281*		*0.3055*		*0.0184*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (500 $\mu l \cdot L^{-1}$)

Table 8. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on yield efficiency in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment	Total yield per tree (kg)		Estimated yield per hectare (ton)	Yield efficiency first harvest ($kg \cdot cm^{-2}$)		Yield efficiency second harvest ($kg \cdot cm^{-2}$)		Total yield efficiency ($kg \cdot cm^{-2}$)	
Control	13.7	ns	39.03	0.08	ns	0.16	ns	0.24	ns
6-BA 100	12.9		36.85	0.10		0.15		0.25	
6-BA 300	13.3		38.07	0.09		0.15		0.24	
ACC 150	14.0		40.03	0.09		0.15		0.24	
ACC 300	13.9		39.58	0.09		0.14		0.23	
ACC 500	13.1		37.28	0.11		0.17		0.28	
6-BA + ACC*	12.1		34.59	0.09		0.13		0.22	
Significance level	*0.7402*		-	*0.6557*		*0.4554*		*0.1931*	
LSD 5%	-		-	-		-		-	
BA vs. ACC	*0.5059*		-	*0.7077*		*0.7078*		*0.5680*	
ACC Linear	*0.4191*		-	*0.2272*		*0.1471*		*0.0435*	
ACC Quadratic	*0.8092*		-	*0.3408*		*0.2291*		*0.0990*	
Control vs. Rest	*0.6285*		-	*0.2570*		*0.5006*		*0.8411*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (500 $\mu l \cdot L^{-1}$)

Table 9. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on harvest distribution and fruit weight in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment	Percentage of fruit picked at first harvest	Percentage of fruit picked at second harvest	Average fruit weight (g)
Control	35.1 ns	65.0 ns	54.1 ns
6-BA 100	39.3	60.7	54.7
6-BA 300	38.2	61.8	52.8
ACC 150	39.0	61.0	56.7
ACC 300	37.6	62.4	56.0
ACC 500	39.8	60.3	55.8
6-BA + ACC*	42.3	57.7	52.3
Significance level	*0.9263*	*0.9263*	*0.1720*
LSD 5%	-	-	-
BA vs. ACC	*0.9944*	*0.9944*	*0.0517*
ACC Linear	*0.8663*	*0.8663*	*0.6463*
ACC Quadratic	*0.7286*	*0.7286*	*0.8155*
Control vs. Rest	*0.3167*	*0.3167*	*0.6347*

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 10. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at first harvest in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment	Average fruit weight at first harvest (g)	Average fruit diameter at first harvest (mm)	Average fruit length at first harvest (mm)	Average fruit length to diameter ratio at first harvest
Control	52.4 ns	43.3 ns	40.7 ns	0.93 ns
6-BA 100	53.5	43.7	40.9	0.94
6-BA 300	51.7	43.1	39.9	0.93
ACC 150	55.3	44.1	40.9	0.93
ACC 300	55.6	43.8	40.9	0.93
ACC 500	53.8	43.9	40.5	0.92
6-BA + ACC*	51.2	42.9	39.8	0.93
Significance level	*0.3089*	*0.4979*	*0.2988*	*0.1162*
LSD 5%	-	-	-	-
BA vs. ACC	*0.1112*	*0.2176*	*0.3845*	*0.3075*
ACC Linear	*0.4560*	*0.8001*	*0.3924*	*0.1072*
ACC Quadratic	*0.6257*	*0.7783*	*0.7925*	*0.1689*
Control vs. Rest	*0.5040*	*0.5943*	*0.7347*	*0.6925*

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 11. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at second harvest in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment	Average fruit weight at second harvest (g)	Average fruit diameter at second harvest (mm)	Average fruit length at second harvest (mm)	Average fruit length to diameter ratio at second harvest
Control	55.7 ns	44.8 ns	41.7 ns	0.94 ns
6-BA 100	55.9	45.2	41.4	0.90
6-BA 300	54.0	44.6	41.2	0.94
ACC 150	58.2	45.8	41.9	0.91
ACC 300	56.4	45.4	41.3	0.91
ACC 500	57.9	45.9	42.0	0.90
6-BA + ACC*	53.5	44.9	40.8	0.92
Significance level	*0.1893*	*0.2129*	*0.2572*	*0.5692*
LSD 5%	-	-	-	-
BA vs. ACC	*0.0599*	*0.0365*	*0.1936*	*0.5895*
ACC Linear	*0.9666*	*0.8517*	*0.7460*	*0.6799*
ACC Quadratic	*0.3435*	*0.3555*	*0.1398*	*0.9529*
Control vs. Rest	*0.8765*	*0.2858*	*0.5628*	*0.2441*

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 12. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit firmness in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment	Average fruit firmness at first harvest (kg)	Average fruit firmness at second harvest (kg)
Control	7.6 ns	7.1 ns
6-BA 100	7.7	6.8
6-BA 300	7.7	6.5
ACC 150	7.3	6.3
ACC 300	7.2	6.0
ACC 500	7.2	6.7
6-BA + ACC*	7.6	6.6
Significance level	*0.2691*	*0.0607*
LSD 5%	-	-
BA vs. ACC	*0.0140*	*0.1112*
ACC Linear	*0.4990*	*0.2242*
ACC Quadratic	*0.8431*	*0.1571*
Control vs. Rest	*0.5746*	*0.0190*

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 13. Effect 1-aminocyclopropane carboxylic acid (ACC) on thinning required in 'Laetitia' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment	Total fruit thinned	Total mass thinned (g)	Average weight of fruitlets thinned (g)
Control	1168	10745	9.2
ACC 300	684	6680	9.8
ACC 400	514	4930	9.6
ACC 500	323	3015	9.3

Table 14. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit set and thinning required in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Average number of fruitlets thinned by hand		Average weight of hand thinned fruitlets (g)	
Control	2597	a	1.4	e
Darwin at full bloom	1359	c	1.8	c
Flower thinning	1890	b	1.7	cd
6-BA 100	2844	a	1.5	de
ACC 400	1371	c	1.8	c
ACC 600	1088	cd	1.9	c
ACC 800	802	de	1.8	c
6-BA + ACC*	835	de	2.0	bc
Darwin + ACC 600	650	e	2.3	a
Darwin + ACC 800	527	e	2.1	ab
Significance level	*<0.0001*		*<0.0001*	
LSD 5%	*325.88*		*0.29*	
ACC vs. ACC + Darwin	*0.0028*		*0.0002*	
ACC Linear	*0.0008*		*0.7373*	
ACC Quadratic	*0.9896*		*0.7770*	
Control vs. Rest	*<0.0001*		*<0.0001*	

***** 6-BA (100 µl·L^{-1}) + ACC (800 µl·L^{-1})

Table 15. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on yield and yield efficiency in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Total yield per tree (kg)		Estimated yield per hectare (ton)	Yield efficiency of first harvest ($kg{\cdot}cm^{-2}$)		Yield efficiency of second harvest ($kg{\cdot}cm^{-2}$)		Yield efficiency of third harvest ($kg{\cdot}cm^{-2}$)		Total yield efficiency ($kg{\cdot}cm^{-2}$)	
Control	9.9	abc	28.1	0.02	ns	0.04	ns	0.10	a	0.16	abcd
Darwin at full bloom	8.6	cd	24.7	0.03		0.04		0.06	bcd	0.13	de
Flower thinning	11.1	a	31.6	0.04		0.05		0.08	abc	0.17	abc
6-BA 100	11.4	a	32.7	0.03		0.05		0.10	a	0.18	a
ACC 400	10.6	ab	30.2	0.03		0.06		0.08	ab	0.17	abc
ACC 600	11.2	a	32.1	0.02		0.05		0.09	ab	0.16	abc
ACC 800	8.0	d	22.8	0.02		0.05		0.05	cd	0.12	e
6-BA + ACC*	10.0	abc	28.3	0.05		0.06		0.06	bcd	0.17	ab
Darwin + ACC 600	8.9	bcd	25.5	0.05		0.05		0.05	cd	0.14	bcde
Darwin + ACC 800	7.9	d	22.4	0.18		0.05		0.04	d	0.14	cde
Significance level	*0.0002*		-	*0.2976*		*0.1320*		*0.0013*		*0.0019*	
LSD 5%	*1.85*		-	-		-		*0.03*		*0.03*	
ACC vs. ACC + Darwin	*0.0691*		-	*0.0397*		*0.9052*		*0.0587*		*0.9844*	
ACC Linear	*0.0070*		-	*0.8904*		*0.1664*		*0.0380*		*0.0015*	
ACC Quadratic	*0.0178*		-	*0.9668*		*0.8041*		*0.1107*		*0.1975*	
Control vs. Rest	*0.8664*		-	*0.5162*		*0.0551*		*0.0074*		*0.6122*	

***** 6-BA (100 $\mu l{\cdot}L^{-1}$) + ACC (800 $\mu l{\cdot}L^{-1}$)

Table 16. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on harvest distribution in '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		Average fruit weight (g)	
Control	13.5	c	26.4	ns	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	19.1	bc	29.1		51.8	ab	52.5	c
ACC 400	18.3	bc	34.8		46.9	abc	59.5	b
ACC 600	15.3	c	33.7		51.0	ab	66.1	a
ACC 800	19.8	bc	42.3		37.9	bcd	64.9	a
6-BA + ACC*	27.6	abc	37.2		35.2	cd	59.5	b
Darwin + ACC 600	32.4	ab	34.8		32.8	cd	66.2	a
Darwin + ACC 800	40.1	a	33.4		26.5	d	64.3	a
Significance level	*0.0161*		*0.2523*		*0.0017*		*<0.0001*	
LSD 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*	

* 6-BA (100 µl·L^{-1}) + ACC (800 µl·L^{-1})

Table 17. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit size and shape at first harvest in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Average fruit weight at first harvest (g)	Average fruit diameter at first harvest (mm)	Average fruit length at first harvest (mm)	Average fruit length to diameter ratio at first harvest
Control	52.0 ef	45.3 e	41.2 de	0.91 a
Darwin at full bloom	60.1 bcd	47.8 cd	43.2 abc	0.90 ab
Flower thinning	56.1 de	46.6 d	42.0 cd	0.90 ab
6-BA 100	51.3 f	45.1 e	40.5 e	0.90 ab
ACC 400	58.3 cd	47.6 cd	42.7 bc	0.90 ab
ACC 600	65.2 a	49.7 a	44.3 a	0.89 b
ACC 800	62.5 abc	48.8 abc	44.0 a	0.90 ab
6-BA + ACC*	60.5 bcd	48.1 bc	43.1 abc	0.90 b
Darwin + ACC 600	65.5 a	49.9 a	43.8 ab	0.88 c
Darwin + ACC 800	63.6 ab	49.4 ab	43.4 ab	0.88 c
Significance level	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
LSD 5%	*4.55*	*1.27*	*1.25*	*0.01*
ACC vs. ACC + Darwin	*0.6433*	*0.3792*	*0.1944*	*<0.0001*
ACC Linear	*0.0680*	*0.0747*	*0.0406*	*0.3486*
ACC Quadratic	*0.0175*	*0.0096*	*0.0990*	*0.1365*
Control vs. Rest	*<0.0001*	*<0.0001*	*0.0002*	*0.0016*

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (800 $\mu l \cdot L^{-1}$)

Table 18. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit size and shape at second harvest in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Average fruit weight at second harvest (g)	Average fruit diameter at second harvest (mm)	Average fruit length at second harvest (mm)	Average fruit length to diameter ratio at second harvest
Control	51.2 e	45.4 c	40.4 d	0.89 ns
Darwin at full bloom	58.1 cd	47.5 bc	41.7 c	0.89
Flower thinning	56.0 d	47.0 bc	41.5 c	0.88
6-BA 100	51.4 e	45.5 c	40.1 d	0.88
ACC 400	59.5 cd	48.1 bc	42.1 bc	0.88
ACC 600	65.1 a	49.7 b	43.3 a	0.87
ACC 800	63.8 ab	49.4 b	43.3 a	0.88
6-BA + ACC*	60.8 bc	48.4 bc	42.6 abc	0.88
Darwin + ACC 600	65.3 a	53.0 a	43.5 a	0.84
Darwin + ACC 800	64.8 ab	49.9 ab	43.2 ab	0.87
Significance level	*<0.0001*	*0.0002*	*<0.0001*	*0.2266*
LSD 5%	*4.05*	*3.13*	*1.14*	-
ACC vs. ACC + Darwin	*0.6611*	*0.0950*	*0.8921*	*0.0720*
ACC Linear	*0.0417*	*0.4093*	*0.0371*	*0.9343*
ACC Quadratic	*0.0559*	*0.5121*	*0.2408*	*0.7704*
Control vs. Rest	*<0.0001*	*0.0066*	*<0.0001*	*0.2085*

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (800 $\mu l \cdot L^{-1}$)

Table 19. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit size and shape at third harvest in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Average fruit weight at third harvest (g)		Average fruit diameter at third harvest (mm)		Average fruit length at third harvest (mm)		Average fruit length to diameter ratio at third harvest	
Control	54.4	d	47.0	ns	41.6	ns	0.89	a
Darwin at full bloom	61.2	bcd	48.8		43.0		0.88	a
Flower thinning	59.6	cd	48.4		42.1		0.87	a
6-BA 100	54.7	d	46.7		40.5		0.87	a
ACC 400	60.7	cd	48.9		41.9		0.86	a
ACC 600	68.0	ab	50.8		43.1		0.85	a
ACC 800	68.5	a	50.7		43.4		0.86	a
6-BA + ACC*	57.3	d	46.0		37.8		0.74	b
Darwin + ACC 600	67.8	ab	51.4		42.7		0.83	a
Darwin + ACC 800	64.6	abc	51.0		42.1		0.83	a
Significance level	*<0.0001*		*0.1858*		*0.1726*		*0.0108*	
LSD 5%	*6.90*		-		-		*0.07*	
ACC vs. ACC + Darwin	*0.4081*		*0.7527*		*0.5475*		*0.3569*	
ACC Linear	*0.0274*		*0.4413*		*0.4569*		*0.9504*	
ACC Quadratic	*0.2556*		*0.6228*		*0.8046*		*0.7840*	
Control vs. Rest	*0.0024*		*0.2028*		*0.8716*		*0.1149*	

* 6-BA (100 µl·L^{-1}) + ACC (800 µl·L^{-1})

Table 20. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit firmness in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Average fruit firmness at first harvest (kg)		Average fruit firmness at second harvest (kg)		Average fruit firmness at third harvest (kg)	
Control	7.1	ns	7.3	a	5.8	ns
Darwin at full bloom	6.8		7.3	a	6.1	
Flower thinning	6.5		7.3	a	5.9	
6-BA 100	6.8		7.1	ab	5.8	
ACC 400	6.3		6.5	cd	5.7	
ACC 600	6.3		6.3	d	5.3	
ACC 800	6.3		7.1	ab	5.7	
6-BA + ACC*	6.6		7.2	a	4.9	
Darwin + ACC 600	6.7		6.9	abc	5.5	
Darwin + ACC 800	6.8		6.7	bcd	5.5	
Significance level	*0.0753*		*<0.0001*		*0.1504*	
LSD 5%	-		*0.48*		-	
ACC vs. ACC + Darwin	*0.0344*		*0.7105*		*0.9664*	
ACC Linear	*0.9191*		*0.0116*		*0.9885*	
ACC Quadratic	*0.9636*		*0.0098*		*0.3170*	
Control vs. Rest	*0.0129*		*0.0738*		*0.5582*	

* 6-BA (100 µl·L^{-1}) + ACC (800 µl·L^{-1})

Table 21. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit pit quality out of 15 fruit in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Average percentage fruit with broken stones at first harvest	Average percentage of fruit with broken stones at second harvest	Average percentage of fruit with broken stones at third harvest
Control	0.03 d	0.03 ns	0.02 ns
Darwin at full bloom	0.10 abcd	0.09	0.01
Flower thinning	0.14 ab	0.03	0.02
6-BA 100	0.05 cd	0.08	0.04
ACC 400	0.07 bcd	0.03	0.00
ACC 600	0.06 bcd	0.05	0.01
ACC 800	0.03 d	0.01	0.01
6-BA + ACC*	0.16 a	0.03	0.01
Darwin + ACC 600	0.12 abc	0.03	0.01
Darwin + ACC 800	0.12 abc	0.01	0.01
Significance level	*0.0149*	*0.0659*	0.0850
LSD 5%	*0.08*	-	-
ACC vs. ACC + Darwin	*0.0114*	*0.5026*	*0.7007*
ACC Linear	*0.2682*	*0.3437*	*0.2785*
ACC Quadratic	*0.7833*	*0.1730*	*1.0000*
Control vs. Rest	*0.0550*	*0.7772*	*0.3737*

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (800 $\mu l \cdot L^{-1}$)

Table 22. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit set and thinning required in 'Fortune' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Average number of fruitlets thinned by hand		Average weight of hand thinned fruitlets (g)	
Control	427	b	7.8	ns
6-BA 500	606	a	6.8	
ACC 200	451	b	7.2	
ACC 400	239	c	7.8	
ACC 600	188	c	7.4	
6-BA + ACC*	149	c	7.9	
Significance level	*<0.0001*		*0.1404*	
LSD 5%	*123.64*		-	
Control vs. ACC	*0.0011*		*0.5100*	
ACC Linear	*<0.0001*		*0.7600*	
ACC Quadratic	*0.1362*		*0.2597*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 23. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on yield and yield efficiency in 'Fortune' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Total yield per tree (kg)		Estimated yield per hectare (ton)	Yield efficiency of first harvest (kg·cm^{-2})		Yield efficiency of second harvest (kg·cm^{-2})		Total yield efficiency (kg·cm^{-2})	
Control	12.3	a	36.4	0.05	ns	0.20	a	0.25	a
6-BA 500	10.9	a	32.3	0.04		0.19	a	0.23	a
ACC 200	12.3	a	36.3	0.04		0.20	a	0.25	a
ACC 400	8.7	b	25.8	0.05		0.12	b	0.17	b
ACC 600	8.1	b	24.1	0.04		0.10	b	0.15	b
6-BA + ACC*	7.8	b	23.2	0.04		0.11	b	0.14	b
Significance level	*<0.0001*		-	*0.7960*		*<0.0001*		*<0.0001*	
LSD 5%	*1.60*		-	*0.03*		*0.05*		*0.05*	
Control vs. ACC	*<0.0001*		-	*0.4614*		*0.0007*		*0.0002*	
ACC Linear	*<0.0001*		-	*0.9726*		*0.0002*		*0.0001*	
ACC Quadratic	*0.0345*		-	*0.3435*		*0.0927*		*0.2209*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 24. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on harvest distribution and fruit weight in '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		Average fruit weight (g)	
Control	21.9	ns	78.1	ns	88.7	bc
6-BA 500	18.4		81.6		85.4	c
ACC 200	18.3		81.7		91.9	abc
ACC 400	31.2		68.7		95.3	ab
ACC 600	29.8		70.2		99.9	a
6-BA + ACC*	27.5		72.5		100.4	a
Significance level	*0.0938*		*0.0938*		*0.0064*	
LSD 5%	-		-		*8.90*	
Control vs. ACC	*0.2911*		*0.2911*		*0.0239*	
ACC Linear	*0.0510*		*0.0510*		*0.0780*	
ACC Quadratic	*0.1512*		*0.1512*		*0.8780*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 25. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at first harvest in 'Fortune' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Average fruit weight at first harvest (g)		Average fruit diameter at first harvest (mm)		Average fruit length at first harvest (mm)		Average fruit length to diameter ratio at first harvest	
Control	100.4	ns	55.7	ab	54.8	ns	0.98	b
6-BA 500	91.8		54.3	b	54.1		1.00	a
ACC 200	100.9		56.0	ab	55.2		0.98	ab
ACC 400	101.7		55.9	ab	54.7		0.98	bc
ACC 600	105.1		57.4	a	56.2		0.98	bc
6-BA + ACC*	105.3		57.4	a	55.8		0.97	c
Significance level	*0.2228*		*0.0363*		*0.4438*		*0.0047*	
LSD 5%	-		*2.04*		-		*0.01*	
Control vs. ACC	*0.5304*		*0.2340*		*0.4524*		*0.2343*	
ACC Linear	*0.4728*		*0.1822*		*0.3699*		*0.2383*	
ACC Quadratic	*0.7875*		*0.3388*		*0.3111*		*0.6393*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 26. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at first harvest in 'Fortune' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Average fruit weight at second harvest (g)		Average fruit diameter at second harvest (mm)		Average fruit length at second harvest (mm)		Average fruit length to diameter ratio at second harvest	
Control	77.0	c	52.1	bcd	51.3	ns	0.98	a
6-BA 500	79.0	c	50.8	d	49.8		0.98	ab
ACC 200	82.9	bc	51.5	cd	50.1		0.97	bc
ACC 400	88.9	ab	52.8	abc	50.7		0.96	d
ACC 600	94.7	a	53.5	ab	51.8		0.97	c
6-BA + ACC*	95.5	a	53.9	a	51.4		0.95	d
Significance level	*<0.0001*		*0.0020*		*0.0964*		*<0.0001*	
LSD 5%	*7.62*		*1.57*		-		*0.01*	
Control vs. ACC	*<0.0001*		*0.1905*		*0.6005*		*<0.0001*	
ACC Linear	*0.0032*		*0.0166*		*0.0334*		*0.6575*	
ACC Quadratic	*0.9583*		*0.6682*		*0.6816*		*0.0119*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 27. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit firmness in 'Fortune' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Average fruit firmness at first harvest (kg)		Average fruit firmness at second harvest (kg)	
Control	8.4	ns	8.2	ns
6-BA 500	9.2		8.1	
ACC 200	8.2		8.3	
ACC 400	8.7		8.3	
ACC 600	8.4		8.6	
6-BA + ACC*	8.4		8.2	
Significance level	*0.0835*		*0.0669*	
LSD 5%	-		-	
Control vs. ACC	*0.9449*		*0.1297*	
ACC Linear	*0.5537*		*0.0510*	
ACC Quadratic	*0.1513*		*0.3111*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 28. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit pit quality out of 15 fruit in 'Fortune' plum at Sandrivier, Wellington district, South Africa (2014/2015).

Treatment	Average percentage of fruit with broken stones at first harvest	Average percentage of fruit with broken stones at second harvest
Control	0.05 ns	0.04 ns
6-BA 500	0.02	0.10
ACC 200	0.02	0.05
ACC 400	0.03	0.07
ACC 600	0.03	0.10
6-BA + ACC*	0.01	0.06
Significance level	*0.4562*	*0.5266*
LSD 5%	-	-
Control vs. ACC	*0.0725*	*0.3467*
ACC Linear	*0.7481*	*0.1881*
ACC Quadratic	*0.5785*	*1.0000*

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 29. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit set and thinning required in '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)
Control	385 a	4.6 a
6-BA 500	412 a	3.9 b
ACC 200	350 a	3.9 b
ACC 400	217 b	3.5 b
ACC 600	171 b	3.7 b
6-BA + ACC*	70 c	3.9 b
Significance level	*<0.0001*	*0.0561*
LSD 5%	*89.09*	*0.72*
Control vs. ACC	*<0.0001*	*0.0025*
ACC Linear	*0.0002*	*0.6548*
ACC Quadratic	*0.2661*	*0.3791*

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 30. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on yield and yield efficiency in in 'Laetitia' plum at Fransmanskraal, Stellenbosch district, South Africa (2014/2015).

Treatment	Total yield per tree (kg)		Estimated yield per hectare (ton)	Total yield efficiency (kg·cm^{-2})		Average fruit weight (g)	
Control	10.7	ab	22.01	0.30	abc	73.0	c
6-BA 500	11.7	a	24.00	0.33	ab	73.2	c
ACC 200	10.9	ab	22.45	0.37	a	74.5	c
ACC 400	9.7	bc	19.88	0.29	bc	87.4	b
ACC 600	8.2	c	16.90	0.23	cd	91.5	b
6-BA + ACC*	5.8	d	11.88	0.17	d	97.6	a
Significance level	*<0.0001*		-	*<0.0001*		*<0.0001*	
LSD 5%	*1.95*		-	*0.07*		*5.75*	
Control vs. ACC	*0.0099*		-	*0.2637*		*<0.0001*	
ACC Linear	*0.0076*		-	*0.0004*		*<0.0001*	
ACC Quadratic	*0.9020*		-	*0.8850*		*0.0824*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 31. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape in 'Laetitia' plum at Fransmanskraal, Stellenbosch district, South Africa (2014/2015).

Treatment	Average fruit diameter (mm)		Average fruit length (mm)		Average fruit length to diameter ratio		Average fruit firmness (kg)	
Control	48.1	c	49.6	c	1.03	a	6.9	a
6-BA 500	48.0	c	49.3	c	1.03	a	6.0	bc
ACC 200	48.4	c	49.6	c	1.02	a	6.8	a
ACC 400	53.1	b	52.9	ab	1.00	b	6.4	ab
ACC 600	54.6	a	52.8	b	0.97	c	6.7	a
6-BA + ACC*	55.4	a	54.5	a	0.98	bc	5.5	c
Significance level	*<0.0001*		*<0.0001*		*<0.0001*		*0.0015*	
LSD 5%	*1.31*		*1.56*		*0.02*		*0.70*	
Control vs. ACC	*<0.0001*		*<0.0001*		*<0.0001*		*0.0474*	
ACC Linear	*<0.0001*		*0.0001*		*<0.0001*		*0.8440*	
ACC Quadratic	*0.0074*		*0.0147*		*0.9424*		*0.2542*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

PAPER 2: The Efficacy of Chemical Thinning Strategies for Peaches (*Prunus persica* (L.) Batsch)

Additional index words. 1-aminocyclopropane-1-carboxylic acid (ACC), 6-benzyladenine (6BA), thinning, yield, fruit quality.

Abstract. **Annual cropping is very important in any deciduous fruit industry and it is believed that annual cropping can be achieved through optimizing thinning practices. Currently peaches are mostly thinned by hand, but there is a great need for chemical thinning strategies in the peach industry. The purpose of this study was to evaluate new thinning strategies on 'Keisie' and 'Sandvliet' peaches. The chemicals evaluated were 1-aminocyclopropane-1-carboxylic acid (ACC) and 6-benzyladenine (6-BA). All the foliar applications were made when the average fruitlet diameter was 8-10 mm. There was a significant thinning effect on 'Keisie' in two seasons. ACC reduced fruit set linearly as the ACC rate increased. No reduction in yield was observed in both seasons and fruit size was not affected. There was a significant reduction in fruit set in 'Sandvliet'. However, hand thinning was not significantly reduced. 'Sandvliet' yield and yield efficiency were significantly reduced indicating that hand thinning was too severe. Due to the reduction in yield, 'Sandvliet' fruit size was significantly improved by ACC at 400 and 600 µl·L^{-1}. Based on two season's data, the recommended rate of ACC for 'Keisie' would be 600 µl·L^{-1} at 8-10 mm fruitlet diameter. Based on our results for one season only, ACC would not currently be recommended on 'Sandvliet'. In both cultivars no split pit was recorded, but slight leaf drop was observed in 'Keisie' and quite severe leaf drop in 'Sandvliet'. Based on what we found in the two seasons 6-BA would not be recommended to be used as a chemical thinner for peaches.**

The South African peach industry covers an area of approximately 7 500 ha (HORTGRO, 2014). Of this, dessert peaches comprise 1 750 ha and cling peaches 5 700 ha (HORTGRO, 2014). In South Africa the cling peach 'Keisie' is the most important at 25% of planted area, while 12% of cling peaches produced in South Africa is 'Sandvliet' (HORTGRO, 2014). In the peach industry, just as in any other deciduous fruit industry, annual cropping is very important and this can be achieved through flower or fruit thinning practices (Stover, 2000). By adjusting the number of fruits on the tree, the remaining fruit will develop to the required size for commercial sales (Day and DeJong, 1998). Peaches are self-fertile, thus not needing any cross pollination and as a result most cultivars set heavy crop loads (Szabó et al., 2000). Fruit trees have self-regulatory mechanisms through which they drop a certain percentage of fruit, but this might not be enough to optimize crop load and the resultant fruit size (Bangerth, 2000).

The fruit growth of peaches can be divided into three main stages; stage I, a rapid increase in size at the beginning of the season consisting mostly of cell division, followed by a slow growth stage II during which pit hardening takes place and ending with stage III, a rapid increase in size due to cell enlargement (Tukey and Einset, 1939; Day and DeJong, 1998). Thinning should take place before or during Stage I to ensure enough assimilates are available for the growth of the remaining fruit (Grossman and DeJong, 1995). The time of thinning is critical, as carbohydrate competition due to heavy flowering and fruit set will lead to smaller fruit (Stover, 2000).

Hand thinning is time consuming and costly and therefore growers wait as long as possible before thinning in order to identify the larger fruit on the tree and to thin selectively (Njoroge and Reighard, 2008). The increase in fruit size does not always compensate for the loss in yield, and a balance between fruit size and yield should be found in order to maximize economic return (Njoroge and Reighard, 2008).

Various chemical thinning agents have been evaluated on peaches in the past, but few have delivered viable results. One approach is reducing return bloom the next season by application of gibberellic acid (GA_3). GA_3 must be applied when flower bud differentiation can be inhibited (Costa and Vizzotto, 2000), and therefore the timing of GA applications are critical (Southwick and Glozer, 2000). This means that the developmental stage of each cultivar has to be known for GA applications to be effective (Southwick and Glozer, 2000).

Applying bloom thinners like hydrogen cyanamide, endothalic acid and pelargonic acid at various rates all reduced fruit set significantly (Fallahi, 1997). One of the advantages of using bloom thinners that damage the pollen and/or the blossoms is that it causes the re-allocation of limited assimilates to the fewer, remaining sinks at an early stage (Fallahi, 1997). In addition, the number of flowers present and climatic conditions that could affect set are known at the time of application (Fallahi, 1997). Southwick et al. (1996) obtained positive results with Armothin® on 'Loadel' cling peach. They applied three concentrations (1%, 3% and 5%) at various developmental stages (80% full bloom, at full bloom and 3 days after full bloom). They found a linear decrease in fruit set with an increase in Armothin® concentration during bloom. A disadvantage of using Armothin® was phytotoxicity, i.e. yellowing of leaves and dieback of young shoots (Southwick et al., 1996). This, however, did not affect the fruit quality or yield when using Armothin® at 5% (Meland, 2007; Southwick et al., 1996). Armothin® was deemed a high risk thinner when applied to 'Sunlite' nectarines at 3% in areas that have a short flowering period, especially when applied early in the flowering period as it lead to over thinning (Coetzee and Theron, 1999).

Fallahi et al. (2006) conducted various trials to evaluate the surfactant Tergitol-TMN-6 as potential chemical thinner on different stone fruit. Concentrations of 10 $ml{\cdot}L^{-1}$, 20 $ml{\cdot}L^{-1}$ and 30 $ml{\cdot}L^{-1}$ applied to peach trees caused severe over thinning, damaged the foliage and significantly lowered the yields. Symptoms of damage occurred as little as two hours after application. Interestingly enough, the concentrations of 10 $ml{\cdot}L^{-1}$ and 20 $ml{\cdot}L^{-1}$ did increase fruit size (Fallahi et al., 2006). Wilkins et al. (2004) evaluated the efficacy of Tergitol-TMN-6 applied once at 10, 20, or 30 $ml{\cdot}L^{-1}$ at full bloom over three years as a chemical thinner on 'Fire Prince' peaches. Tergitol-TMN-6 caused widespread necrosis of flower parts and effectively reduced the crop load at 10 $ml{\cdot}L^{-1}$ more than at 20 and 30 $ml{\cdot}L^{-1}$, which was unexpected. The authors concluded that Tergitol-TMN-6 is an effective blossom thinner at 10 $ml{\cdot}L^{-1}$ (Wilkins et al., 2004). Previously they compared Tergitol-TMN-6 to TMN-10 (yleneoxyethanol) at full bloom and at petal fall at 20 $ml{\cdot}L^{-1}$ and 40 $ml{\cdot}L^{-1}$. From this they concluded that both of the chemicals caused necrosis to several parts of the tree, both thinned trees and reduced the amount of hand thinning from approximately 780 fruit to 200 fruit per tree (Wilkins et al., 2004).

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). Studies on mung beans confirmed that 1-aminocyclopropane-1-carboxylic acid (ACC), a precursor of ethylene, increased the rate of ethylene production (Yoshii and Imaseki, 1981). ACC is currently being evaluated as a new chemical thinner in pome fruit (Schupp et al., 2012). Studies on 'Early Amber' peaches with Ethrel (Ethephon) resulted in adequate fruit thinning at a concentration of 30 $\mu l{\cdot}L^{-1}$ (Buchanan et al., 1970). Exogenously applied

Ethephon increases ethylene levels in plants (Wertheim, 1997) and therefore a similar response to that of Ethephon is expected with ACC application.

The purpose of this study was to evaluate the efficacy of ACC and 6-BA applied at the fruitlet stage to two peach cultivars on fruit set, yield and fruit quality. The main purpose of 6-BA in this study was to try and prevent any phytotoxicity/leaf drop possibly induced by the ACC.

Materials and methods

Plant material and site description for the 2013/2014 season. In 2013/2014, a trial was conducted on the cling peach 'Keisie in an orchard situated in the Warm Bokkeveld on the farm Jagerskraal (33^{o}18'01.5"S 19^{o}19'42.3"E) near Ceres in the Western Cape, South Africa. Trees on SAPO 778 rootstock were planted in 1998 at 4.5 m x 1.5 m and trained to a conventional "Kers en blaker" central leader system characterized by strong lower scaffold branches and a triangular tree shape.

Experimental layout for the 2013/2014 season. Two products were evaluated, viz., ACC (VBC 30160; Philagro SA Pty (Ltd.), Somerset West, South Africa) and 6-BA (MaxCel™; Philagro SA Pty (Ltd.), Somerset West, South Africa). Seven treatments were used as summarized in Table 1. A randomized complete block design with eight single tree replicates was used. All the foliar applications were made using a motorized knapsack sprayer (STIHL, Pietermaritzburg, South Africa) when the average fruitlet size was 7-14 mm. Each tree was sprayed for 30 seconds, thus applying approximately 1 L of solution per tree under slow drying conditions when the temperature was between 10 to 15 ^{o}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 climatic conditions following the applications for the trial was favorable for at least five days with temperatures above 18 ^{o}C. Dates of chemical application, hand thinning and harvests are summarized in Table 2.

Plant and site description for the 2014/2015 season. Trials were conducted on the cling peach cultivars Keisie and Sandvliet. The trial on 'Keisie' was in the same orchard as the previous season, but on different trees. The 'Sandvliet' orchard was near Bonnievale in the Western Cape, South Africa, on the farm Lucerne (33^{o}50'57.6"S 19^{o}57'59.9"E). The

‘Sandvliet’ trees on GF677 rootstocks were planted in 1997 at 3 m x 5.5 m and trained to a “Kers en blaker” system.

Experimental layout for the 2014/2015 season. Both trials consisted of six treatments in a randomized complete block design with 10 single tree replicates as summarized in Table 3. Dates of chemical application, hand thinning and harvests are summarized in Table 4. For both trials at least one tree was left between the treated trees that served as a buffer tree to prevent drift effects. A buffer row was left as well where more than one row was used for a trial.

As in the previous season, all the foliar applications were made using a motorized knapsack sprayer when the average fruitlet size was 8-10 mm. The conditions following the applications for all the trials were favorable for at least five days with temperatures above 18 ^{o}C.

Data collection. The same data were recorded in all the trials. Fruit set was determined in the lower half of the tree canopy on eight tagged one-year-old shoots (± 45 cm in length) per tree in 2013/2014 and five similar length one-year-old shoots per tree in 2014/2015. At full bloom, the number of flowers on the tagged shoots was counted. After the application of the treatments a period of at least two weeks was allowed for fruitlets to drop. Prior to commercial hand thinning, all fruit that set on tagged shoots were counted. Hand thinning was done according to standard commercial practice. 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 and after harvest the trunk cross sectional area measured to determine total yield efficiency expressed as kg fruit per trunk cross sectional area ($kg{\cdot}cm^{-2}$). A sample of 30 fruit per treatment replicate 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 split pit. Fruit firmness was determined using the GÜSS texture analyzer with an 11.1 mm probe. (Guss electronic model GS 20, Strand, South Africa) while split pit was recorded as either present or not.

Statistical analysis. The data were analyzed using SAS Enterprise guide 5.1 (SAS Institute Inc., Cary, North Carolina, USA) using the linear model procedure and the pairwise t-test to determine the Least Significant Difference (LSD) when the F-statistic indicated significance at P<0.05. Single degree of freedom, orthogonal, polynomial contrasts were fitted where applicable.

Results

Results for the 2013/2014 season. All the ACC treatments significantly reduced average fruit set on eight tagged one-year-old 'Keisie' shoots per tree compared to the control (Table 5). An increase in ACC rate resulted in a linear decrease in the percentage fruit set, while 6-BA did not reduce fruit set. The two higher ACC rates (300 $\mu l \cdot L^{-1}$ and 500 $\mu l \cdot L^{-1}$) reduced fruit set significantly compared to the 6-BA treatments. The ACC 500 $\mu l \cdot L^{-1}$ in combination with 6-BA 100 $\mu l \cdot L^{-1}$ reduced fruit set significantly more than the ACC 500 $\mu l \cdot L^{-1}$ did on its own. Slight leaf drop was observed in this trial (data not shown). The two higher ACC rates, the high 6-BA (300 $\mu l \cdot L^{-1}$) application and the 6-BA and ACC combination treatment reduced the number of fruitlets that had to be thinned by hand commercially compared to the control. The increase in ACC rate resulted in a linear decrease in required hand thinning (Table 5). The average weight of the thinned fruitlets did not differ significantly between treatments, but there was a trend (p=0.0762) for thinning treatments to on average decrease the average weight of thinned fruit compared to the control. No significant differences were found in the total yield per tree, total yield efficiency per tree or yield efficiency at any of the four harvest dates (Table 6 and 7). ACC increased yield efficiency linearly with increasing rate at the first harvest date while the two 6-BA treatments increased the yield efficiency at the fourth harvest date compared to the ACC treatments. This altered the harvest distribution with a linear increase on the first and linear decrease on the fourth harvest date in the percentage fruit picked with an increase in ACC rate (Table 8). On the second harvest date a higher percentage fruit was picked from ACC treated trees than from 6-BA treated trees. The inverse was observed at the fourth harvest date.

The ACC 500 $\mu l \cdot L^{-1}$ treatment significantly increased average fruit diameter compared to the control at the first harvest date with a linear increase in the average fruit diameter as the ACC rate increased, resulting in a small decrease in fruit length to diameter ratio at the two highest ACC rates (Table 9). ACC on average also increased fruit diameter and decreased the length to diameter ratio at the first harvest date compared to the 6-BA treatments. Treatments did not affect average fruit weight or length at the first harvest. There was a significant effect on the average fruit shape (ratio of diameter to length) for the first harvest, but not of any horticultural importance (Table 9). The treatments had no significant influence on fruit size at the other harvest dates (Table 10 to12). There was a significant linear decrease with increasing ACC rate in fruit firmness at the first harvest date, while at the fourth harvest date the high rate of 6-BA reduced fruit firmness compared to all treatments accept ACC 500 µl·L^{-1} (Table 13). Split pit incidence ranged from 0 to 6.7% throughout the trial and treatments did not differ significantly from each other (data not shown).

Results for the 2014/2015 season: 'Keisie'. All ACC treatments significantly reduced the average fruit set on the five tagged one-year-old shoots compared to the control (Table 14). There was a linear decrease in the average fruit set as the ACC rate increased, while 6-BA had no significant effect on the average fruit set. 6-BA in combination with the highest ACC rate reduced fruit set more than the highest ACC rate (600 µl·L^{-1}) alone. The addition of 6-BA to the high ACC rate reduced leaf drop (Fig. 1). The two higher ACC rates reduced the hand thinning requirement during commercial thinning compared to the control with a linear decrease in thinning requirement as the ACC rate increased (Table 14). 6-BA significantly reduced the fruitlets that needed to be thinned by hand. 6-BA was the only treatment that increased the average weight of the hand thinned fruitlets (Table 14).

No significant differences were found in the total yield or total yield efficiency per tree (Tables 15 and 16). However, there was a linear decrease in yield efficiency at the third harvest as the ACC rate increased (Table 16). At the fourth harvest date the yield efficiency of the 6-BA and ACC combination treatment was significantly lower than all the other treatments except the high rate of ACC alone (Table 16). The ACC treatments did alter the harvest distribution. Most fruit were picked at the first harvest, but significantly so for the high rate of ACC with 6-BA (Table 17). The inverse was recorded at the fourth harvest. There was a linear decrease in the percentage fruit picked as the ACC rate increased at the third harvest.

The overall average fruit weight was not affected by any treatment (Table 17). The treatments had no significant effect on the average fruit size (weight, diameter and length) throughout all harvests except for a significant increase in the average fruit diameter at the second harvest date for the ACC treatments compared to the control (Table 18-20). A linear decrease in the average fruit length at the second and third harvest was found as the ACC rate increased, with a resultant decrease in the length to diameter ratio of the fruit. 6-BA had no significant effect on fruit size (weight, diameter or length) (Table 18-20). There was a significant effect on the average fruit shape for the second and third harvest, but not of any horticultural importance (Table 19-20). There was a linear decrease in the average fruit firmness as the ACC rate increased during the second harvest and the highest ACC rate increased firmness compared to the control (Table 21). Split pit incidence ranged from 0 to 6.7% throughout the trial and treatments did not differ significantly (data not shown).

Results for the 2014/2015 season: 'Sandvliet'. Severe leaf drop was observed in this trial, especially at the highest ACC rate (600 $\mu l \cdot L^{-1}$) as shown in Fig. 2. The addition of 6-BA did not reduce leaf drop. All ACC rates significantly reduced the average fruit set on five tagged one-year-old shoots compared to the untreated control with a linear decrease in fruit set as the ACC rate increased (Table 22). 6-BA had no significant effect on the average fruit set on the tagged shoots. The combinational treatment decreased fruit set similar to the ACC 400 $\mu l \cdot L^{-1}$ treatment and less than ACC 600 $\mu l \cdot L^{-1}$ on its own. None of the treatments significantly reduced the number of fruitlets that had to be thinned by hand during commercial hand thinning (Table 22). The average weight of the fruitlets thinned by hand were significantly lower for the two higher ACC rates (400 $\mu l \cdot L^{-1}$and 600 $\mu l \cdot L^{-1}$) and the combination treatment compared to the control (Table 22). The two higher ACC rates and the combination treatment induced significantly lower total yield and total yield efficiency compared to the control and the 6-BA and lower rate of ACC (Table 23). In general an increase in ACC rate linearly reduced yield and yield efficiency. The harvest distribution of this trial was significantly altered with higher rates of ACC linearly advancing harvesting at first harvest with the inverse effect at the second harvest date (Table 24). On average ACC treatment increased fruit weight with a significant increase at the two higher rates. The combination treatment also increased fruit weight, but 6-BA had no effect (Table 24). ACC on average increased the average fruit size (weight, diameter and length) compared to the control during the first harvest, with a linear increase in fruit weight as the ACC rate increased (Table 25). The two higher ACC rates significantly increased fruit weight and diameter compared to the control while the highest rate significantly increased fruit length. There was a linear increase in fruit weight and fruit diameter as the ACC rate increased. There was a significant effect on the average fruit shape for the first harvest, but not of any horticultural importance (Table 25). No differences occurred at the second harvest date

(Table 26). No effect on fruit firmness was observed during this trial (Table 27) and no split pit occurred.

Discussion

'Keisie'. During both seasons ACC reduced the average fruit set linearly with increasing rate, and there was an added reduction in fruit set when 6-BA was combined with the highest ACC rates (500 µl·L^{-1} and 600 µl·L^{-1}). This added thinning effect of 6-BA was surprising as the 6-BA was added to prevent leaf drop or phytotoxicity. The thinning effect may be due to 6-BA stimulating the growth of lateral side shoots (Green and Autio, 1990; Elfving and Cline, 1993) increasing the IAA transport out of all the newly released lateral vegetative buds and correlatively inhibiting IAA transport from fruit, thus leading to the abscission of weaker fruitlets (Bangerth, 2000). The reduction in fruit set corresponded with the data on the number of fruitlets that had to be thinned by hand during commercial hand thinning. In both seasons the lower ACC rates (150 µl·L^{-1} and 200 µl·L^{-1}, respectively) were unable to reduce the hand thinning requirement. Schupp et al. (2012) also found a linear response in thinning efficacy in 'Golden Delicious' apples with increasing rates of ACC from 100, 300, and 500 mg·L^{-1} and we found a similar dose rate response in thinning Japanese plums (Paper 1). Schupp et al. (2012) also found that ACC at 300 mg·L^{-1} gave a similar response as Ethephon at the same rate in 'Golden Delicious'. As mentioned before, in both seasons the added 6-BA to the highest ACC rates (500 µl·L^{-1} and 600 µl·L^{-1}) resulted in further fruit set reduction, but not on the hand thinning requirement. The tagged one-year-old shoots were in the lower tree canopy while the hand thinning requirement reflects the fruit set situation throughout the whole canopy. In South Africa, delayed foliation often results in trees flowering later in the upper canopy and fruitlets were probably smaller here than in the lower canopy and therefore possibly less susceptible to the ACC (Theron, 2013).

During the first season ACC treatments did not improve fruit size or reduce yield efficiency; therefore the ACC rate was increased in the second season. Even though stronger fruit thinning was the result, total yield efficiency was not affected. Schupp et al. (2012) found that, in 'Golden Delicious' apples fruit set, and the required thinning were significantly reduced, but this also reduced the yield linearly as the rate of ACC increased. However, fruit size was significantly increased, which we did not observe in the two 'Keisie' trials. In contrast, we were able to significantly increase the fruit size of 'African Rose™', 'Fortune' and 'Laetitia' plums with ACC applied at 600 µl·L^{-1} (Paper 1). In both seasons ACC slightly advanced fruit maturity with more fruit harvested earlier and a slight decrease in fruit firmness at the first two harvest dates compared to the control. The same effect was previously observed in apples and plums where fruit maturity showed a clear response to crop load with advanced maturity on low-cropping trees (Wünsche et al., 2000; Paper 1).

'Sandvliet'. The severe leaf drop observed in this trial is a concern. We expected the same slight leaf drop response we observed on 'Keisie', but 'Sandvliet' is known to be more sensitive to adverse conditions, e.g. free lime in the soil (G.F.A. Lötze, personal communication). Although all of the ACC treatments, including the combination treatment, significantly reduced the fruit set, none of these treatments reduced the commercial hand thinning requirement, which was unexpected. Also, these treatments did reduce yield and yield efficiency. A possible explanation for this is that the team of laborers that did the commercial hand thinning over thinned trees as fruitlets could be seen more clearly due to the leaf drop resulting in low yield and yield efficiency.

All the chemical treatments altered the harvest distribution, with a linear increase in the percentage fruit harvested earlier. As mentioned earlier, this negative correlation between crop load and fruit maturation has been observed in other fruit crops as well (Wünsche et al., 2000; Paper 1). As expected, the reduction in set and yield of the ACC treatments led to significantly larger fruit even though substantial leaf drop occurred. This reduction in yield and increase in fruit size is similar to what Schupp et al. (2012) found when using ACC on 'Golden Delicious' apples where they recorded a linear reduction in yield and concomitant increase in fruit size. We found similar results for Japanese plums (Paper 1). In this trial this effect was mainly observed during the first harvest where all the fruit size parameters (weight, diameter and length) increased. However the improvement in average fruit size could not compensate for the drastic reduction in yield. Although fruit size was increased, possibly through enhanced fruit growth during stage I before pit hardening, no split pit was observed.

Conclusion

The thinning effect of ACC in 'Keisie' was very consistent and promising. From our trials it appears that the recommended rate to thin 'Keisie' would be 600 $\mu l \cdot L^{-1}$. There is some concern regarding the considerable yield reduction obtained in the 'Sandvliet' trial. However, as mentioned, this might be due to laborers over thinning or that the rates of ACC were too high for this more sensitive cultivar, as indicated by the more severe leaf drop. Further research is needed to determine optimum ACC concentrations for different peach cultivars. The addition of 6-BA to ACC would not be recommended as a thinning strategy due to the erratic results obtained over the course of two seasons.

Literature cited

Bangerth, F. 2000. Abscission and thinning of young fruit and their regulation by plant hormones and bioregulators. Plant Growth Regul. 31(1):43–59. Available at: http://dx.doi.org/10.1023/A:1006398513703.

Buchanan, D.W., R.H. Biggs, J.A. Blake, and W.B. Sherman. 1970. Peach thinning with 3CPA and Ethrel during cytokinesis. J. Amer. Soc. Hort. Sci. 95:781–784. (abstr.).

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

Coetzee, J.H. and K.I. Theron. 1999. Efficacy of Armothin as a chemical thinner applied during different flowering stages of 'Sunlite' nectarines. HortScience 9(1):8–12.

Costa, G. and G. Vizzotto. 2000. Fruit thinning of peach trees. Plant Growth Regul. 31:113–119.

Day, K.R. and T.M. DeJong. 1998. Improving fruit size: Thinning and girdling nectarines, peaches, and plums. The Compact Fruit Tree 32(2):1–6.

Elfving, D.C. and RA Cline. 1993. Benzyladenine and other chemicals for thinning Empire apple trees. J. Amer. Soc. Hort. Sci. 118:593–598.

Fallahi, E. 1997. Applications of endothalic acid, pelagronis acid, and hydrogen cyanamide for blossom thinning in apple and peach. Hortechnology 7(4):395–399.

Fallahi, E., B. Fallahi, J. McFerson, R.E. Byers, 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(5):1243–1248.

Green, D.W., W.R. Autio, 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. DeJong. 1995. Maximum fruit growth potential and seasonal patterns of resource dynamics during peach growth. Ann. Bot-London 75:553–560.

HORTGRO. 2014. http://www.hortgro.co.za/market-intelligence-statistics/key-deciduous-fruit-statistics/

Meland, M., 2007. Efficacy of chemical bloom thinning agents to European plums. Acta Agr. Scand. B-S P 57(3):235–242.

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.

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(9):1308-1311.

Southwick, S.M. and K. Glozer. 2000. Reducing flowering with gibberellins to increase fruit size in stone fruit trees: Applications and implications in fruit production. HortTechnology 10(4):744–751.

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(2):334–338.

Stover, E. 2000. Relationship of flowering intensity and cropping in fruit species. HortTechnology 10(4):729–732.

Szabó, Z., J. Nyéki, and L. Szalay. 2000. Auto fertility of peach varieties in a variety collection. Acta Hort. 538:131-134.

Theron, K.I. 2013. Chemical thinning of Apple: South African Perspective. Acta Hort. 998:85-90.

Tukey, H.B., and O. Einset. 1939. Effect of fruit thinning on size, colour and yield of peaches and on growth and blossoming of the tree. Amer. Soc. Hort. Sci. 36:314–319.

Wertheim, S.J. 1997. Chemical thinning of deciduous fruit trees. Acta Hort. 463:445–462.

Wilkins, B.S., R.C. Ebel, W.A. Dozier, J. Pitts, and R. Boozer. 2004. Tergitol TMN-6 for thinning peach blossoms. HortScience 39(7):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(1):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-l-carboxylic acid (ACC) and ACC synthase. Plant Cell Physiol. 22(3):369–379 (abstr.).

Table 1. Treatment specifications for trials done with 6-benzyladenine (BA) and 1-aminocyclopropane carboxylic acid (ACC) on 'Keisie' cling peaches in the season of 2013/2014.

Treatments
Untreated control
6-benzyladenine (6-BA) (100 µl·L^{-1}) at 8-10 mm fruit diameter*
6-benzyladenine (6-BA) (300 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (150 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (300 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (500 µl·L^{-1}) at 8-10 mm fruit diameter*
6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1}) at 8 -10 mm fruit diameter*

* Actual average fruitlet diameter at application was 7-14 mm

Table 2. Summary of the dates of treatment application, follow up hand thinning of fruitlets and harvest for 'Keisie' cling peach in the season of 2013/2014.

Phenological stage	Date
Application	23 Sept. 2013
Follow up hand thinning of fruitlets	7 Oct. 2013
Harvest	20, 23, 27 Jan. 2014 and 04 Feb. 2014

Table 3. Treatment specifications for trials done with 6-benzyladenine (BA) and 1-aminocyclopropane carboxylic acid (ACC) on the cling peach cultivars Keisie and Sandvliet in the season of 2014/2015.

Treatments
Untreated control
6-BA (100 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (200 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (400 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (600 µl·L^{-1}) at 8-10 mm fruit diameter*
6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1}) at 8-10 mm fruit diameter*

* Actual average fruitlet diameter at application was 7-10 mm for 'Keisie' and 10.95 mm for 'Sandvliet'

Table 4. Summary of the dates of treatment application, follow up hand thinning of fruitlets and harvest for 'Keisie' and 'Sandvliet' cling peach in the season of 2014/2015.

Phenological stage	'Keisie'	'Sandvliet'
Application	12 Sept. 2014	4 Sept. 2014
Follow up hand thinning of fruitlets	25 Sept. 2014	23 Sept. 2014
Harvest	9, 14, 20, 29 Jan. 2015	6, 15 Jan. 2015

Table 5. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit set and thinning required in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2013/2014).

Treatment	Average fruit set on 8 1-yr-old shoots		Average number of fruitlets thinned by hand		Average weight of hand thinned fruitlets (g)	
Control	85.2	a	871	a	2.4	ns
6-BA 100	82.4	a	755	ab	2.6	
6-BA 300	78.8	ab	669	bc	2.5	
ACC 150	74.3	b	740	ab	2.6	
ACC 300	62.0	c	589	cd	2.7	
ACC 500	54.6	c	464	d	2.8	
6-BA + ACC*	45.0	d	493	d	2.6	
Significance level	*<0.0001*		*<0.0001*		*0.2009*	
LSD 5%	*7.61*		*141.45*		-	
BA vs. ACC	*<0.0001*		*0.0155*		*0.1168*	
ACC Linear	*<0.0001*		*0.0003*		*0.1968*	
ACC Quadratic	*0.2439*		*0.5876*		*0.7963*	
Control vs. Rest	*<0.0001*		*<0.0001*		*0.0762*	

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 6. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on yield and yield efficiency in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2013/2014).

Treatment	Total yield per tree (kg)		Estimated yield per hectare (ton)	Yield efficiency first harvest (kg·cm^{-2})		Yield efficiency second harvest (kg·cm^{-2})	
Control	37.4	ns	55.4	0.06	ns	0.10	ns
6-BA 100	39.3		58.3	0.05		0.09	
6-BA 300	36.7		54.4	0.05		0.09	
ACC 150	37.4		55.4	0.05		0.11	
ACC 300	40.1		59.4	0.06		0.10	
ACC 500	37.9		56.1	0.07		0.12	
6-BA + ACC*	39.5		58.6	0.07		0.10	
Significance level	*0.9684*		-	*0.1960*		*0.5271*	
LSD 5%	-		-	-		-	
BA vs. ACC	*0.8694*		-	*0.1180*		*0.0697*	
ACC Linear	*0.9492*		-	*0.0245*		*0.3653*	
ACC Quadratic	*0.4651*		-	*0.9709*		*0.4379*	
Control vs. Rest	*0.7216*		-	*0.8940*		*0.8226*	

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 7. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on yield efficiency in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2013/2014).

Treatment	Yield efficiency third harvest ($kg \cdot cm^{-2}$)	Yield efficiency fourth harvest ($kg \cdot cm^{-2}$)	Total yield efficiency ($kg \cdot cm^{-2}$)
Control	0.08 ns	0.06 ns	0.30 ns
6-BA 100	0.10	0.09	0.32
6-BA 300	0.08	0.08	0.31
ACC 150	0.08	0.06	0.30
ACC 300	0.09	0.07	0.32
ACC 500	0.07	0.04	0.31
6-BA + ACC*	0.08	0.06	0.31
Significance level	*0.4756*	*0.0772*	*0.9793*
LSD 5%	-	-	-
BA vs. ACC	*0.2339*	*0.0047*	*0.5748*
ACC Linear	*0.3295*	*0.1636*	*0.8824*
ACC Quadratic	*0.3503*	*0.2981*	*0.5385*
Control vs. Rest	*0.7114*	*0.7097*	*0.7426*

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (500 $\mu l \cdot L^{-1}$)

Table 8. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on harvest distribution and fruit weight in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2013/2014).

Treatment	Percentage of fruit picked at first harvest	Percentage of fruit picked at second harvest	Percentage of fruit picked at third harvest	Percentage of fruit picked at fourth harvest	Average weight of fruit (g)
Control	17.0 ns	34.6 ab	25.4 ns	23.0 ab	195.2 ns
6-BA 100	13.6	27.0 c	30.1	29.4 a	203.6
6-BA 300	14.7	30.6 bc	25.8	28.9 a	188.6
ACC 150	13.9	33.3 abc	25.6	27.1 a	196.7
ACC 300	17.4	32.3 bc	27.3	23.1 ab	200.6
ACC 500	22.0	39.4 a	22.6	15.9 b	199.8
6-BA + ACC*	19.8	33.5 abc	24.6	22.1 ab	196.2
Significance level	*0.1426*	*0.0435*	*0.4366*	*0.0390*	*0.5822*
LSD 5%	-	*7.00*	-	*8.56*	-
BA vs. ACC	*0.1063*	*0.0083*	*0.2029*	*0.0130*	*0.5547*
ACC Linear	*0.0215*	*0.0689*	*0.3190*	*0.0108*	*0.7089*
ACC Quadratic	*0.9963*	*0.2276*	*0.3030*	*0.8424*	*0.7077*
Control vs. Rest	*0.9663*	*0.4755*	*0.8037*	*0.6695*	*0.6803*

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (500 $\mu l \cdot L^{-1}$)

Table 9. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at first harvest in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2013/2014).

Treatment	Average fruit weight at first harvest (g)		Average fruit diameter at first harvest (mm)		Average fruit length at first harvest (mm)		Average fruit length to diameter ratio at first harvest	
Control	202.7	ns	70.8	bc	65.7	ns	0.93	a
6-BA 100	211.5		72.1	abc	67.0		0.93	a
6-BA 300	198.3		70.3	c	64.7		0.92	abc
ACC 150	210.2		71.5	bc	66.0		0.92	ab
ACC 300	215.8		72.8	ab	66.2		0.91	c
ACC 500	222.0		73.8	a	67.1		0.91	c
6-BA + ACC*	211.9		72.7	ab	66.5		0.91	bc
Significance level	*0.2858*		*0.0266*		*0.2476*		*0.0073*	
LSD 5%	-		*2.11*		-		*0.01*	
BA vs. ACC	*0.0872*		*0.0292*		*0.3574*		*0.0117*	
ACC Linear	*0.2371*		*0.0384*		*0.2779*		*0.0526*	
ACC Quadratic	*0.9531*		*0.7726*		*0.7274*		*0.1743*	
Control vs. Rest	*0.2438*		*0.0920*		*0.4809*		*0.0411*	

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 10. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at second harvest in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2013/2014).

Treatment	Average fruit weight at second harvest (g)		Average fruit diameter at second harvest (mm)		Average fruit length at second harvest (mm)		Average fruit length to diameter ratio at second harvest	
Control	200.1	ns	70.4	ns	64.2	ns	0.91	ns
6-BA 100	206.9		71.4		65.2		0.91	
6-BA 300	193.3		70.0		64.0		0.91	
ACC 150	192.9		70.1		63.5		0.91	
ACC 300	200.6		71.2		64.8		0.91	
ACC 500	199.8		71.1		64.4		0.91	
6-BA + ACC*	198.9		71.3		64.3		0.90	
Significance level	*0.7842*		*0.6788*		*0.8670*		*0.5276*	
LSD 5%	-		-		-		-	
BA vs. ACC	*0.7015*		*0.9137*		*0.6467*		*0.1873*	
ACC Linear	*0.4888*		*0.3514*		*0.5011*		*0.8572*	
ACC Quadratic	*0.5618*		*0.4761*		*0.3944*		*0.4762*	
Control vs. Rest	*0.8476*		*0.5933*		*0.8461*		*0.5706*	

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 11. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at third harvest in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2013/2014).

Treatment	Average fruit weight at third harvest (g)	Average fruit diameter at third harvest (mm)	Average fruit length at third harvest (mm)	Average fruit length to diameter ratio at third harvest
Control	209.1 ns	72.2 ns	65.5 ns	0.91 ns
6-BA 100	212.5	72.7	66.4	0.91
6-BA 300	192.1	70.4	63.6	0.90
ACC 150	206.0	71.8	65.1	0.91
ACC 300	210.6	72.5	65.7	0.91
ACC 500	205.2	72.1	65.1	0.90
6-BA + ACC*	197.7	71.3	64.4	0.90
Significance level	*0.4575*	*0.4140*	*0.2877*	*0.5389*
LSD 5%	-	-	-	-
BA vs. ACC	*0.4697*	*0.3810*	*0.6848*	*0.3315*
ACC Linear	*0.9000*	*0.7972*	*0.9225*	*0.3924*
ACC Quadratic	*0.5951*	*0.5462*	*0.5265*	*0.7913*
Control vs. Rest	*0.5362*	*0.6751*	*0.5824*	*0.6157*

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 12. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at fourth harvest in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2013/2014).

Treatment	Average fruit weight at fourth harvest (g)	Average fruit diameter at fourth harvest (mm)	Average fruit length at fourth harvest (mm)	Average fruit length to diameter ratio at fourth harvest
Control	168.8 ns	68.3 ns	61.4 ns	0.90 ns
6-BA 100	183.4	70.9	63.3	0.89
6-BA 300	171.0	68.5	61.4	0.90
ACC 150	177.8	69.4	62.3	0.90
ACC 300	175.3	69.1	62.0	0.90
ACC 500	172.3	68.5	61.3	0.90
6-BA + ACC*	176.3	68.9	61.8	0.90
Significance level	*0.7719*	*0.5644*	*0.5835*	*0.9553*
LSD 5%	-	-	-	-
BA vs. ACC	*0.7325*	*0.4536*	*0.5431*	*0.5784*
ACC Linear	*0.5574*	*0.4940*	*0.3634*	*0.6473*
ACC Quadratic	*0.9819*	*0.9314*	*0.8861*	*0.8875*
Control vs. Rest	*0.3202*	*0.3838*	*0.5123*	*0.4333*

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 13. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit firmness in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2013/2014).

Treatment	Average fruit firmness at first harvest (kg)	Average fruit firmness at second harvest (kg)	Average fruit firmness at third harvest (kg)	Average fruit firmness at fourth harvest (kg)
Control	9.2 a	9.1 ns	8.6 ns	8.2 a
6-BA 100	9.1 ab	8.6	8.2	8.2 a
6-BA 300	8.3 dc	9.1	8.2	7.1 b
ACC 150	9.1 ab	9.3	8.2	8.1 a
ACC 300	8.5 bcd	9.4	8.3	7.9 a
ACC 500	8.1 d	9.0	8.2	7.6 ab
6-BA + ACC*	8.9 abc	9.3	8.6	7.9 a
Significance level	*0.0031*	*0.2095*	*0.6332*	*0.0328*
LSD 5%	*0.63*	-	-	*0.70*
BA vs. ACC	*0.5093*	*0.0699*	*0.7377*	*0.4919*
ACC Linear	*0.0037*	*0.3736*	*0.8579*	*0.1485*
ACC Quadratic	*0.6606*	*0.2730*	*0.7390*	*0.9718*
Control vs. Rest	*0.0331*	*0.8314*	*0.1894*	*0.1549*

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 14. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit set and thinning required in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2014/2015).

Treatment	Average fruit set on 5 1-yr-old shoots	Average number of fruitlets thinned by hand	Average weight of hand thinned fruitlets (g)
Control	88.9 a	1061 a	3.1 b
6-BA 100	88.1 a	758 b	4.0 a
ACC 200	68.1 b	912 ab	2.9 b
ACC 400	59.4 b	881 b	3.1 b
ACC 600	47.9 c	553 c	3.1 b
6-BA + ACC*	28.8 d	542 c	3.1 b
Significance level	*<0.0001*	*<0.0001*	*<0.0001*
LSD 5%	*9.32*	*177.00*	*0.39*
Control vs. ACC	*<0.0001*	*<0.0001*	*0.8858*
ACC Linear	*<0.0001*	*0.0002*	*0.1941*
ACC Quadratic	*0.7124*	*0.0577*	*0.6885*

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 15. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on yield and yield efficiency in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2014/2015).

Treatment	Total yield per tree (kg)		Estimated yield per hectare (ton)	Yield efficiency first harvest ($kg \cdot cm^{-2}$)		Yield efficiency second harvest ($kg \cdot cm^{-2}$)	
Control	38.2	ns	56.6	0.09	ns	0.08	ns
6-BA 100	37.8		56.0	0.09		0.08	
ACC 200	35.6		52.8	0.09		0.07	
ACC 400	38.9		57.7	0.08		0.08	
ACC 600	32.9		48.8	0.10		0.07	
6-BA + ACC*	34.3		50.8	0.12		0.06	
Significance level	*0.3202*		-	*0.1581*		*0.2727*	
LSD 5%	-		-	-		-	
Control vs. ACC	*0.2619*		-	*0.4195*		*0.3182*	
ACC Linear	*0.3792*		-	*0.4233*		*0.4306*	
ACC Quadratic	*0.0888*		-	*0.1563*		*0.1059*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$)

Table 16. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on yield efficiency in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2014/2015).

Treatment	Yield efficiency third harvest ($kg \cdot cm^{-2}$)		Yield efficiency fourth harvest ($kg \cdot cm^{-2}$)		Total yield efficiency ($kg \cdot cm^{-2}$)	
Control	0.08	ab	0.02	ab	0.27	ns
6-BA 100	0.09	a	0.03	a	0.28	
ACC 200	0.09	a	0.02	ab	0.28	
ACC 400	0.09	a	0.03	a	0.29	
ACC 600	0.07	b	0.02	bc	0.26	
6-BA + ACC*	0.06	b	0.01	c	0.25	
Significance level	*0.0175*		*0.0033*		*0.4731*	
LSD 5%	*0.03*		*0.01*		-	
Control vs. ACC	*0.7795*		*0.7013*		*0.7908*	
ACC Linear	*0.0337*		*0.1001*		*0.4134*	
ACC Quadratic	*0.2708*		*0.0064*		*0.2869*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$)

Table 17. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on harvest distribution and fruit weight in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, 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		Percentage of fruit picked at fourth harvest		Average fruit weight (g)	
Control	32.9	bc	29.3	ns	29.2	abc	8.6	ab	171.6	ns
6-BA 100	29.7	bc	27.5		33.2	ab	9.5	a	172.2	
ACC 200	32.7	bc	24.2		34.3	a	8.9	ab	171.0	
ACC 400	27.4	c	28.8		32.5	ab	11.3	a	166.1	
ACC 600	39.7	ab	28.5		26.4	bc	5.4	bc	166.4	
6-BA + ACC*	45.0	a	26.6		23.8	c	4.6	c	167.1	
Significance level	*0.0130*		*0.5041*		*0.0424*		*0.0061*		*0.7824*	
LSD 5%	*10.32*		-		*7.46*		*3.73*		-	
Control vs. ACC	*0.4226*		*0.3093*		*0.9805*		*0.4861*		*0.3845*	
ACC Linear	*0.1765*		*0.1393*		*0.0391*		*0.0672*		*0.4259*	
ACC Quadratic	*0.0549*		*0.3222*		*0.5138*		*0.0127*		*0.6016*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 18. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at first harvest in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2014/2015).

Treatment	Average fruit weight at first harvest (g)		Average fruit diameter at first harvest (mm)		Average fruit length at first harvest (mm)		Average fruit length to diameter ratio at first harvest	
Control	189.7	ns	68.2	ns	63.0	ns	0.92	ns
6-BA 100	188.3		68.3		63.4		0.93	
ACC 200	184.8		67.9		62.7		0.92	
ACC 400	167.5		61.3		62.1		0.83	
ACC 600	185.2		68.1		61.6		0.91	
6-BA + ACC*	180.3		67.4		56.7		0.91	
Significance level	*0.4375*		*0.4321*		*0.4616*		*0.4685*	
LSD 5%	-		-		-		-	
Control vs. ACC	*0.2674*		*0.5188*		*0.4446*		*0.5061*	
ACC Linear	*0.9690*		*0.9527*		*0.8583*		*0.8142*	
ACC Quadratic	*0.0870*		*0.0529*		*0.0748*		*0.0724*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 19. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at second harvest in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2014/2015).

Treatment	Average fruit weight at second harvest (g)		Average fruit diameter at second harvest (mm)		Average fruit length at second harvest (mm)		Average fruit length to diameter ratio at second harvest	
Control	172.2	ns	66.9	b	62.2	ns	0.93	a
6-BA 100	171.9		66.4	b	61.7		0.93	a
ACC 200	172.7		70.4	a	61.4		0.87	b
ACC 400	172.6		70.4	a	60.6		0.86	c
ACC 600	165.1		69.3	a	59.4		0.86	c
6-BA + ACC*	169.1		69.6	a	60.7		0.87	b
Significance level	*0.8550*		*<0.0001*		*0.0657*		*<0.0001*	
LSD 5%	-		*1.86*		-		*0.01*	
Control vs. ACC	*0.6688*		*0.0001*		*0.0262*		*<0.0001*	
ACC Linear	*0.2718*		*0.2679*		*0.0372*		*0.0016*	
ACC Quadratic	*0.5315*		*0.4955*		*0.7888*		*0.3916*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 20. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at third harvest in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2014/2015).

Treatment	Average fruit weight at third harvest (g)		Average fruit diameter at third harvest (mm)		Average fruit length at third harvest (mm)		Average fruit length to diameter ratio at third harvest	
Control	153.0	ns	64.9	ns	59.6	ab	0.92	cd
6-BA 100	156.5		65.4		60.5	ab	0.93	bc
ACC 200	155.6		65.0		61.2	a	0.94	a
ACC 400	158.2		65.5		60.9	a	0.93	b
ACC 600	149.0		64.5		58.7	b	0.91	de
6-BA + ACC*	151.8		64.9		58.8	b	0.91	e
Significance level	*0.7472*		*0.8933*		*0.0312*		*0.0001*	
LSD 5%	-		-		*1.84*		*0.01*	
Control vs. ACC	*0.9059*		*0.9720*		*0.7049*		*0.2973*	
ACC Linear	*0.3147*		*0.5569*		*0.0104*		*0.0001*	
ACC Quadratic	*0.3051*		*0.3480*		*0.2280*		*0.2442*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 21. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit firmness in 'Keisie' cling peach at Jagerskraal, Warm Bokkeveld, South Africa (2014/2015).

Treatment	Average fruit firmness at first harvest (kg)		Average fruit firmness at second harvest (kg)		Average fruit firmness at third harvest (kg)	
Control	7.86	ns	8.5	ab	7.1	ns
6-BA 100	8.10		8.7	a	7.3	
ACC 200	7.40		8.3	ab	7.2	
ACC 400	6.83		8.1	abc	7.1	
ACC 600	7.54		7.5	c	7.0	
6-BA + ACC*	8.00		8.0	bc	6.9	
Significance level	*0.3043*		*0.0125*		*0.8540*	
LSD 5%	-		*0.67*		-	
Control vs. ACC	*0.3837*		*0.0383*		*0.6794*	
ACC Linear	*0.8165*		*0.0182*		*0.4874*	
ACC Quadratic	*0.2194*		*0.4353*		*0.8983*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 22. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit set and thinning required in 'Sandvliet' cling peach at Lucerne, Bonnievale, South Africa (2014/2015).

Treatment	Average fruit set on 5 1-yr-old shoots		Average number of fruitlets thinned by hand		Average weight of hand thinned fruitlets (g)	
Control	68.5	a	1298	ns	5.7	a
6-BA 100	62.7	ab	1539		5.1	ab
ACC 200	56.4	b	1396		5.1	ab
ACC 400	40.0	c	976		4.4	b
ACC 600	21.9	d	1159		4.6	b
6-BA + ACC*	34.6	c	935		4.5	b
Significance level	*<0.0001*		*0.4426*		*0.0082*	
LSD 5%	*8.02*		-		*0.72*	
Control vs. ACC	*<0.0001*		*0.5041*		*0.0009*	
ACC Linear	*<0.0001*		*0.4913*		*0.1728*	
ACC Quadratic	*0.8162*		*0.3124*		*0.1356*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 23. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on yield and yield efficiency in 'Sandvliet' cling peach at Lucerne, Bonnievale, South Africa (2014/2015).

Treatment	Total yield per tree (kg)		Estimated yield per hectare (ton)	Yield efficiency first harvest (kg cm^{-2})		Yield efficiency second harvest (kg cm^{-2})		Total yield efficiency (kg cm^{-2})	
Control	67.4	a	40.9	0.18	ab	0.10	a	0.28	a
6-BA 100	66.2	a	40.1	0.20	a	0.08	b	0.28	a
ACC 200	62.1	a	37.6	0.19	ab	0.06	b	0.25	ab
ACC 400	44.8	b	27.2	0.15	bc	0.03	c	0.18	bc
ACC 600	29.6	b	17.9	0.11	c	0.01	c	0.11	c
6-BA + ACC*	43.3	b	26.2	0.18	ab	0.02	c	0.20	b
Significance level	*<0.0001*		-	*0.0111*		*<0.0001*		*<0.0001*	
LSD 5%	*15.50*		-	*0.05*		*0.03*		*0.07*	
Control vs. ACC	*0.0006*		-	*0.2639*		*<0.0001*		*0.0006*	
ACC Linear	*<0.0001*		-	*0.0041*		*0.0002*		*0.0003*	
ACC Quadratic	*0.8791*		-	*0.9066*		*0.7568*		*0.9752*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 24. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on harvest distribution and fruit weight in 'Sandvliet' cling peach at Lucerne, Bonnievale, South Africa (2014/2015).

Treatment	Percentage of fruit picked at first harvest		Percentage of fruit picked at second harvest		Average fruit weight (g)	
Control	62.9	c	37.1	c	138.5	bc
6-BA 100	72.4	b	27.6	b	133.7	c
ACC 200	73.7	b	26.3	b	148.0	ab
ACC 400	83.3	a	16.7	a	150.3	a
ACC 600	88.9	a	11.1	a	155.1	a
6-BA + ACC*	89.6	a	10.4	a	154.7	a
Significance level	*<0.0001*		*<0.0001*		*0.0020*	
LSD 5%	*7.15*		*7.15*		*11.76*	
Control vs. ACC	*<0.0001*		*<0.0001*		*0.0052*	
ACC Linear	*0.0001*		*0.0001*		*0.2252*	
ACC Quadratic	*0.5201*		*0.5201*		*0.8066*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 25. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at first harvest in 'Sandvliet' cling peach at Lucerne, Bonnievale, South Africa (2014/2015).

Treatment	Average fruit weight at first harvest (g)	Average fruit diameter at first harvest (mm)	Average fruit length at first harvest (mm)	Average fruit length to diameter ratio at first harvest
Control	145.9 c	65.8 cd	56.2 cd	0.85 ab
6-BA 100	137.1 c	64.4 d	55.3 d	0.86 a
ACC 200	148.9 bc	66.5 bc	56.7 bcd	0.85 ab
ACC 400	160.4 ab	68.5 a	57.5 abc	0.84 c
ACC 600	165.0 a	68.6 a	58.1 ab	0.85 bc
6-BA + ACC*	159.3 ab	67.9 ab	58.4 a	0.86 a
Significance level	*0.0003*	*0.0002*	*0.0036*	*0.0061*
LSD 5%	*12.38*	*1.89*	*1.66*	*0.01*
Control vs. ACC	*0.0138*	*0.0087*	*0.0299*	*0.3314*
ACC Linear	*0.0120*	*0.0307*	*0.0918*	*0.3585*
ACC Quadratic	*0.5109*	*0.2483*	*0.8992*	*0.0363*

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$)

Table 26. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at second harvest in 'Sandvliet' cling peach at Lucerne, Bonnievale, South Africa (2014/2015).

Treatment	Average fruit weight at second harvest (g)	Average fruit diameter at second harvest (mm)	Average fruit length at second harvest (mm)	Average fruit length to diameter ratio at second harvest
Control	131.0 ns	64.0 ns	57.8 ns	0.90 ns
6-BA 100	130.2	64.2	57.4	0.90
ACC 200	147.1	66.6	59.8	0.90
ACC 400	140.2	65.2	58.2	0.89
ACC 600	129.9	59.2	53.0	0.81
6-BA + ACC*	150.0	66.4	59.3	0.89
Significance level	*0.2364*	*0.4356*	*0.4372*	*0.4092*
LSD 5%	-	-	-	-
Control vs. ACC	*0.2102*	*0.9109*	*0.9313*	*0.4575*
ACC Linear	*0.1157*	*0.0599*	*0.0550*	*0.0826*
ACC Quadratic	*0.8545*	*0.5009*	*0.5526*	*0.3649*

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$)

Table 27. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit firmness in ‘Sandvliet’ cling peach at Lucerne, Bonnievale, South Africa (2014/2015).

Treatment	Average fruit firmness at first harvest (kg)	Average fruit firmness at second harvest (kg)
Control	7.3 ns	7.1 ns
6-BA 100	7.3	7.1
ACC 200	7.1	6.8
ACC 400	7.6	6.8
ACC 600	7.8	6.0
6-BA + ACC*	7.4	6.5
Significance level	*0.2676*	*0.2276*
LSD 5%	-	-
Control vs. ACC	*0.3028*	*0.1691*
ACC Linear	*0.0356*	*0.0992*
ACC Quadratic	*0.5294*	*0.3682*

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

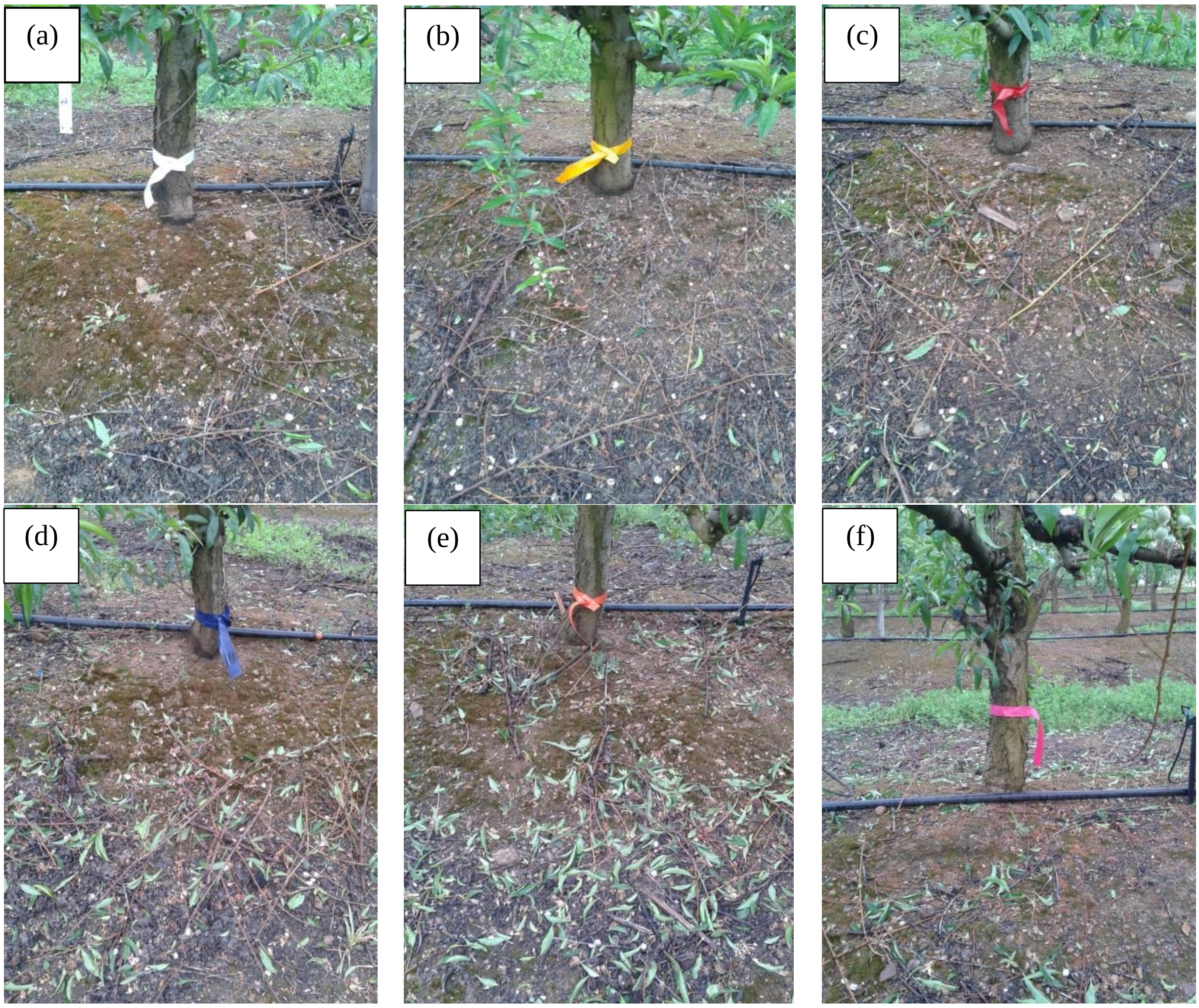

Fig 1. Effect of different chemical thinning applications on leaf drop observed under 'Keisie' trees at Jagerskraal, Warm Bokkeveld in the 2014/15 season. (a) untreated control, (b) 6-BA 100 µl·L^{-1}, (c) ACC 200 µl·L^{-1}, (d) ACC 400 µl·L^{-1}, (e) ACC 600 µl·L^{-1} and (f) ACC 600 µl·L^{-1} + 6-BA 100 µl·L^{-1}.

Fig. 2. Effect of chemical thinning application on leaf drop/phytotoxicity observed on 'Sandvliet' trees at Lucerne, Bonnievale in the 2014/2015 season. (a) Untreated control, and (b) ACC 600 $\mu l \cdot L^{-1}$.

PAPER 3: The Efficacy of Chemical Thinning Strategies for Nectarines (*Prunus persica* (L.) Batsch var. *nucipersica*)

Additional index words. 1-aminocyclopropane-1-carboxylic acid (ACC), 6-benzyladenine (6-BA), Darwin 300™, thinning, yield, fruit quality.

***Abstract.* The purpose of this study was to evaluate new chemical thinning strategies for 'Turquois', 'Alpine' and 'August Red' nectarines. The chemicals evaluated were 1-aminocyclopropane-1-carboxylic acid (ACC) and 6-benzyladenine (6-BA). These were also combined with mechanical thinning utilizing the Darwin 300™ or hand thinning during bloom on 'Alpine'. All the foliar applications were made when the average fruitlet size was 8-10 mm. A significant thinning effect was found only in the 'Turquoise' trial at the highest ACC rate (500 µl·L^{-1}), but it resulted in a significant reduction in total yield. A significant reduction in fruit set was also induced by 300 µl·L^{-1} 6-BA on 'Turquoise'. No effect on 'Turquoise' fruit size was obtained, but a slight increase in fruit firmness was observed for the two higher ACC rates. In 'Alpine', none of the ACC or 6-BA treatments reduced the average fruit set significantly compared to the control and slight ACC induced leaf drop was observed. The Darwin 300™ reduced fruit set significantly compared to flower hand thinning. The Darwin 300™ and hand flower thinning reduced the hand thinning requirement at commercial hand thinning significantly. The yield efficiency increased quadratically up until the ACC 400 µl.L-^{1} with none of the ACC treatments differing from the control. The yield efficiency of ACC 400 µl·L-1 was significantly higher than both combination treatments between ACC and Darwin 300™. The combination treatment of ACC with the Darwin 300™ shifted harvest distribution earlier, but did not increase fruit size. ACC decreased 'Alpine' fruit firmness significantly as the rate increased. No effect on fruit set or hand thinning requirement was found with ACC or 6-BA on 'August Red'. This resulted in no effect on yield efficiency or fruit size, but harvest distribution was shifted slightly earlier. Slight ACC-induced leaf drop occurred in 'August Red' as well. ACC would not be recommended for thinning of nectarines at this stage and further studies are needed.**

The South African nectarine industry covers an area of approximately 2 300 ha (HORTGRO, 2014). In South Africa, Alpine is the most important nectarine cultivar at 15% of the planted area while with 6% of the area planted, August Red is the second most important cultivar (HORTGRO, 2014). 'Alpine' matures early in the season, approximately mid-November (Week 47), while 'August Red' is later maturing at the start of February (Week 6) (ARC Infruitec-Nietvoorbij, 2014). Nectarines are self-fertile, but fruit set from either self-pollination or open pollination is weaker in nectarines compared to peaches (Nyéki et al., 1998). Fruit set is, however, still high and considerable hand thinning is needed for the remaining fruit to develop the required size (Day and DeJong, 1998).

Hand thinning is time consuming and costly and therefore growers wait as long as possible before thinning in order to identify the larger fruit on the tree and to thin small fruit selectively (Njoroge and Reighard, 2008). The resultant increase in fruit size does not always compensate for the loss in yield, and a balance between fruit size and yield should be found in order to maximize economic return (Njoroge and Reighard, 2008).

One thinning approach is to reduce return bloom the next season by application of gibberellic acid (GA_3). Gibberellins are translocated from the fruit to nearby nodes and inhibit the initiation of new floral primordial (Webster and Spencer, 2000). Therefore, applying GA_3 during flower induction will reduce flower numbers and therefore fruit number, which should lead to a reduction in hand thinning costs (Gonzalez-Rossia et al., 2006). Coetzee and Theron (1999b) obtained positive results with GA_3 (Ralex®) on 'Sunlite' nectarines. They applied four concentrations (90, 120, 150 and 180 $mg{\cdot}L^{-1}$) four weeks before harvest and between the first and second harvest dates. All of the treatments reduced the number of reproductive buds and increased the number of vegetative buds in the subsequent season. The earlier application did have an over thinning effect. Coetzee and Theron (1999b) found no interaction between the concentration of the chemical and the time of application.

Applying bloom thinners like hydrogen cyanamide, endothalic acid and pelargonic acid at various rates all reduced fruit set in 'Redhaven' peaches significantly (Fallahi, 1997). One of the advantages of using bloom thinners that damage the pollen and/or the blossoms is that it causes the re-allocation of limited assimilates to the fewer, remaining sinks at an early stage (Fallahi, 1997). In addition, the number of flowers present and climatic conditions that could affect set are known at the time of application (Fallahi, 1997). Armothin®, a surfactant, was deemed a high risk thinner when applied to 'Sunlite' nectarines at 3% in areas that have a short flowering period especially when applied early in the flowering period as it lead to over thinning (Coetzee and Theron, 1999a).

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). Studies on mung beans confirmed that 1-aminocyclopropane-1-carboxylic acid (ACC), a precursor of ethylene, increased ethylene production (Yoshii and Imaseki, 1981). ACC is currently being evaluated as a new chemical thinner in pome fruit (Schupp et al., 2012). Exogenously applied Ethephon increases ethylene levels in plants (Wertheim, 1997) and therefore a similar response to that of Ethephon is expected with ACC application.

Mechanical thinning is a relatively new development in the stone fruit industry and can be used to remove both flowers and fruitlets (Theron et al., 2015; Miller et al., 2011). The effect of mechanical thinning is immediate and not influenced by climatic conditions (Martin et al., 2010). Hand thinning time could be reduced by 28% by mechanical thinning using a pneumatic hand held shaker resulting in economic savings up to 26% in peaches, but this shaker did not remove enough green fruit (Martin et al., 2010). More recently De Villiers (2014) evaluated the Darwin 300™ on three nectarines, viz. 'Zephyr', 'Summer Fire' and 'Royal Sun'. The required hand thinning time of 'Zephyr' was reduced by 43% in the first season and by 33% in the second season. Similar results were obtained for 'Summer Fire' and 'Royal Sun'.

The purpose of this study was to evaluate the efficacy of new chemical thinning strategies, i.e. ACC and 6-BA applied at the fruitlet stage, on fruit set, yield and fruit quality of various nectarine cultivars. The main purpose of 6-BA in this study was to try and prevent any phytotoxicity/leaf drop possibly induced by the ACC. The chemical thinning treatments were also combined with mechanical thinning on 'Alpine' utilizing the Darwin 300™ or hand thinning during bloom.

Materials and methods

Plant material and site description for the 2013/2014 season. In the 2013/2014 season one trial was conducted on the cultivar Turquoise in an orchard situated in the Warm Bokkeveld on the farm Vreeland (33°20'43.0"S 19°18'34.1"E) near Ceres in the Western

Cape, South Africa. Trees on 'Viking' rootstock were planted in 2010 at 4 m x 1.5 m and trained to a Slender Spindle system.

Experimental layout for the 2013/2014 season. Two products were evaluated, viz. ACC (VBC 30160; Philagro SA Pty (Ltd.), Somerset West, South Africa) and 6-BA (MaxCel™; Philagro SA Pty (Ltd.), Somerset West, South Africa). Seven treatments were used as summarized in Table 1. A randomized complete block design with eight single tree replications was used. All the foliar applications were made using a motorized knapsack sprayer (STIHL, Pietermaritzburg, South Africa) when the average fruitlet size was 8-12 mm. Each tree was sprayed for 30 seconds, thus applying approximately 1L of treatment solution per tree under slow drying conditions at temperatures between 10 and 15 ^{o}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 climatic conditions following the applications were favorable for at least five days with maximum temperatures above 18 ^{o}C. Dates of chemical application, hand thinning and harvests are summarized in Table 2.

Plant material and site description for the 2014/2015 season. Trials were conducted on two nectarines, 'Alpine' and 'August Red'. The 'Alpine' orchard is near Riebeek-Kasteel in the Western Cape, South Africa on the farm Swartdam (33^{o}25'28.32"S 18^{o}53'48.7"E). The 'Alpine' trees on 'Flordaguard' rootstocks were planted in 2009 at 4 m x 2 m and trained to a double leader, in-the-row, planting system. The 'August Red' orchard is near Ceres in the Koue Bokkeveld in the Western Cape, South Africa on the farm Bo-Bokfontein (32^{o}49'14.4"S 19^{o}16'01.2"E). The 'August Red' trees on 'SAPO 778' rootstocks were planted at 4 m x 1.5 m and trained to a Slender Spindle system.

Experimental layout of the 2014/2015 season. The 'Alpine' trial consisted of 10 treatments in a randomized complete block design with 10 replicates as summarized in Table 3. For the mechanical thinning treatments, each replicate consisted of five trees with the middle tree used to record data. Mechanical thinning was done using the Darwin 300™ at 160 rpm and a tractor speed of 4.8 km·h^{-1}. For the chemical and flower thinning treatments single tree plots were used. The flower thinning treatment was done by removing approximately two thirds of the available flowers on a shoot, a third from the distal part and a third from the basal part of the shoot. Dates of treatment application, hand thinning and harvests are summarized in Table 4. The 'August Red' trial consisted of six treatments in a randomized complete block design with 10 replicates as summarized in Table 5. Dates of treatment application, hand thinning and harvests are summarized in Table 6.

All the foliar applications were made using a motorized knapsack sprayer, when the average fruitlet size was 8-10 mm as described for the previous season. In all trials, at least one tree was left between the treated trees that served as a buffer tree to prevent drift effects. A buffer row was left as well where more than one row was used for a trial. The climatic conditions following the applications for both trials were favorable for at least five days with maximum temperatures above 18 ^{o}C.

Data collection. The same data were recorded in all trials. Fruit set was determined in the lower half of the tree canopy on eight tagged one-year-old shoots (± 45 cm in length) per tree in 2013/2014 and five similar length one-year-old shoots per tree in 2014/2015. At full bloom the flowers on the tagged shoots were counted. At least two weeks were allowed for fruitlets to drop after the chemical application. Prior to commercial hand thinning, all fruit that set on tagged shoots were counted. Hand thinning was done according to the standard commercial practices. All fruitlets thinned by hand were collected and brought to the laboratory, weighed and counted. At each commercial harvest date the yield per tree was recorded and after harvest the trunk cross sectional area was calculated to determine total yield efficiency expressed as kg fruit per trunk cross sectional area (kg·cm^{-2}). 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 split pit. Fruit firmness was determined using the GÜSS texture analyzer with an 11.1 mm probe (Guss electronic model GS 20, Strand, South Africa), while split pit was recorded as either present or not.

Statistical analysis. The data were analyzed using SAS Enterprise guide 5.1 (SAS Institute Inc., Cary, North Carolina, USA) using the linear model procedure and the pairwise t-test to determine the Least Significant Difference (LSD) when the F-statistic indicated significance at $P<0.05$. Single degree of freedom, orthogonal, polynomial contrasts were fitted where applicable.

Results

Results for the 2013/2014 season: 'Turquoise'. All ACC treatments significantly reduced average fruit set on the eight tagged one-year-old shoots compared to the control (Table 7). The increase in ACC rate from 150 to 500 µl·L^{-1} resulted in a linear decrease in the percentage fruit set. The higher 6-BA rate (300 µl·L^{-1}) reduced fruit set slightly but significantly compared to the control (Table 7). The two higher ACC rates (300 µl·L^{-1} and 500 µl·L^{-1}) and the combinational ACC and 6-BA treatment reduced fruit set significantly compared to the 6-BA treatments. The highest ACC rate (500 µl·L^{-1}) alone or in combination with 6-BA reduced the number of fruitlets that had to be thinned by hand commercially compared to the control and the 6-BA treatments (Table 7). The increase in ACC rate resulted in a linear decrease in required hand thinning. The average weight of the thinned fruitlets differed significantly between treatments, with an increase in ACC rate resulting in a linear decrease in the average weight of hand thinned fruitlets (Table 7). ACC-induced leaf drop was observed in this trial (Table 7; Fig 1). There was a quadratic increase in leaf drop as the ACC rate increased with the two higher rates resulting in severe leaf drop. The addition of 100 µl·L^{-1} 6-BA to ACC 500 µl·L^{-1} did reduce the leaf drop significantly compared to the ACC 300 µl·L^{-1} and ACC 500 µl·L^{-1}. 6-BA reduced leaf drop significantly compared to all treatments, including the control.

The highest ACC rate (500 µl·L^{-1}) and the combination treatment reduced the total yield per tree significantly compared to the control (Table 8). This was also reflected in total yield efficiency where the highest ACC rate (500 µl·L^{-1}) alone and in combination with 6-BA reduced the total yield efficiency significantly compared to all other treatments. However, there was a linear decrease in total yield efficiency as the ACC rate increased (Table 8). There was a linear decrease in yield efficiency for the first harvest date with an increasing ACC rate and the highest ACC rate differed significantly from the control (Table 9). At the second harvest, the yield efficiency increased quadratically until ACC 300 µl·L^{-1} where after it decreased again, but there was no significant difference between treatments. No differences were observed in yield efficiency at the third harvest, but yield efficiency of the 6-BA treated trees at the fourth harvest was significantly higher compared to all other treatments. The two 6-BA treatments delayed harvesting with a lower percentage of fruit picked compared to

ACC at the second harvest and a higher percentage of fruit picked at the fourth harvest compared to all other treatments (Table 10).

None of the treatments had any effect on the average fruit weight of the entire crop (Table 10) and size (weight, diameter and length) at any harvest (Table 11 to 13). Fruit shape (ratio of length to diameter) was slightly affected at the second harvest but these differences are of no horticultural significance (Table 12). The average fruit firmness at the second harvest of the two higher ACC rates (300 $\mu l{\cdot}L^{-1}$ and 500 $\mu l{\cdot}L^{-1}$) and the combination treatment was significantly higher compared to the control (Table 14). This is reflected in the quadratic increase in the average fruit firmness as the ACC rate increased. The average fruit firmness for two higher ACC rates was also significantly higher than the two 6-BA treatments and the lowest ACC rate (Table 14). The average fruit firmness for the third harvest date showed a quadratic response to ACC rate in that fruit from the 300 $\mu l{\cdot}L^{-1}$ rate was significantly less firm than the 500 $\mu l{\cdot}L^{-1}$ but not the 150 $\mu l{\cdot}L^{-1}$ rate (Table 14). The fruit firmness for the highest ACC rate with and without 6-BA was significantly higher compared to the control at the third harvest (Table 14). Split pit levels ranged from 3.5% and zero and were of no horticultural significance (data not shown).

Results from the 2014/2015 season: 'Alpine'. None of the ACC treatments significantly reduced the average fruit set on five tagged shoots compared to the control (Table 15). The fruit set on the five tagged shoots of the two lower ACC rates (200 $\mu l{\cdot}L^{-1}$ and 400 $\mu l{\cdot}L^{-1}$), the ACC in combination with 6-BA and the Darwin 300™ in combination with ACC 400 $\mu l{\cdot}L^{-1}$ treatment was significantly lower than set of the flower thinning treatment and the combination treatment between the Darwin 300™ and ACC 600 $\mu l{\cdot}L^{-1}$. The Darwin 300™ at full bloom reduced fruit set on the tagged shoots significantly compared to the flower thinning treatment. Both the Darwin 300™ and hand flower thinning treatment at full bloom as well as the Darwin 300™ in combination with ACC significantly reduced the average fruit set on five tagged shoots. Both the Darwin 300™ and hand flower thinning treatment at full bloom as well as the Darwin 300™ in combination with ACC significantly reduced the number of fruitlets that had to be thinned by hand during commercial hand thinning compared to the control (Table 15). None of the ACC treatments reduced the number of fruitlets that had to be thinned by hand; however, there was a quadratic increase in the number of fruitlets that had to be thinned by hand since ACC 400 $\mu l{\cdot}L^{-1}$ but not 600 $\mu l{\cdot}L^{-1}$

increased the thinning requirement compared to ACC 200 µl·L^{-1}. ACC in combination with the Darwin 300™ did not cause an additional thinning effect when compared to the Darwin 300™ alone. 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. 6-BA had no effect on the average weight of the thinned fruitlets compared to the control (Table 15). The average weight of the thinned fruitlets of the Darwin 300™ and the flower thinning treatments as well as ACC in combination with the Darwin 300™ was significantly higher compared to the control. ACC 600 µl·L^{-1} decreased the average weight of thinned fruitlets compared to the control. Slight ACC-induced leaf drop was observed, and the added 6-BA did not reduce leaf drop (Fig. 2).

The total yield per tree of the ACC treatments, 6-BA on its own or in combination with ACC as well as the Darwin 300™ and flower thinning treatments at full bloom did not differ from the control (Table 16). The total yield per tree for the ACC treatments increased quadratically with the middle rate (400 µl·L^{-1}) resulting in a significantly higher yield than the lower and higher rates. The combination of ACC 400 µl·L^{-1} or 600 µl·L^{-1} and the Darwin 300™ significantly reduced total yield per tree compared to these respective ACC treatments on their own and also compared to the control. The yield efficiency increased quadratically as the ACC rate increased with ACC 400 µl·L^{-1} giving a significantly higher yield efficiency compared to the lower and higher rates (Table 16). The two Darwin 300™ and ACC combination treatments reduced yield efficiency compared to the control and flower thinning. The yield efficiency of ACC 400 µl·L^{-1} was significantly higher than both ACC and Darwin 300™ combination treatments. Data on yield efficiency for each individual harvest date is presented in Annexure D. The Darwin 300™ at full bloom, hand flower thinning and the two ACC and Darwin 300™ combination treatments increased average fruit weight compared to the control (Table 16). None of the ACC treatments increased the average fruit weight for this trial significantly compared to the control. 6-BA did not increase fruit weight and none of the treatments decreased average fruit weight compared to the control (Table 16).

The ACC/Darwin 300™ combinations resulted in slightly more fruit harvested during the first harvest and considerably more fruit harvested during the second harvest compared to the ACC treatments on their own (Table 17). Also the Darwin 300™ on its own and the flower thinning treatment led to significantly more fruit picked during the second harvest compared to the control and all ACC treatments, as well as the 6-BA treatment. The percentage fruit harvested during the third harvest for the ACC and Darwin 300™

combination treatments were significantly higher than ACC 400 µl·L^{-1} treatment, but not higher than the Darwin 300™ treatment alone. A greater proportion of fruit from the Darwin 300™ treatment compared to the control was harvested at the third harvest. The percentage fruit harvested during the fourth harvest from the control trees was significantly lower than all treatments except 6-BA, ACC 400 µl·L^{-1} and ACC 600 µl·L^{-1}. The percentage fruit harvested at the forth harvest for the ACC and Darwin 300™ combination treatments were significantly higher than that of the ACC 600 µl·L^{-1}. On average, more fruit was harvested from control trees than any treated trees at the fifth harvest date, but treatment differences were not significant (Table 18). There was a linear increase in percentage fruit harvested during the sixth and seventh harvests as the ACC rate increased. The percentage fruit harvested for the Darwin 300™ was also significantly lower during the sixth harvest compared to the control (Table 18). The percentage fruit harvested during the seventh harvest of the two higher ACC rates (400 µl·L^{-1} and 600 µl·L^{-1}) was significantly higher compared to the two ACC and Darwin 300™ combination treatments). These two combination treatments were significantly lower than the control. The percentage fruit harvested during the eighth harvest from all the ACC treated trees was significantly higher compared to that of the two ACC and Darwin 300™ combination treatments and the Darwin 300™ treatment alone. These latter three treatments were significantly lower than all treatments except flower thinning.

Data on fruit size and shape, as well as fruit firmness for each individual harvest date is presented in Annexure D. ACC and 6-BA had no effect on the average fruit diameter compared to the control (Table 19). The Darwin 300™, flower thinning and the two ACC and Darwin 300™ combination treatments significantly increased the average fruit diameter and length compared to the control. Flower thinning also significantly increased the average fruit length compared to the control. The average fruit diameter and length of the ACC and Darwin 300™ combination treatments was significantly higher compared to ACC alone. ACC and 6-BA had no effect on the average fruit length compared to the control, except for ACC 600 µl·L^{-1} that had a significantly lower average fruit length (Table 19). Fruit shape (ratio of length to diameter) was slightly affected in this trial, but these differences are of no horticultural significance (Table 19). The two higher ACC rates (400 µl·L^{-1} and 600 µl·L^{-1}) and the Darwin 300™ and 600 µl·L^{-1} ACC combination significantly reduced the average fruit firmness compared to the control and the Darwin 300™ and ACC 400 µl·L^{-1}

combination (Table 19). Split pit incidence ranged from 0 to 6.7% throughout the trial and treatments did not differ significantly from each other (data presented in Annexure D).

'August Red'. There was no significant effect on the average fruit set on tagged shoots on 'August Red' (Table 20). None of the treatments significantly reduced the number of fruitlets that had to be thinned by hand during commercial hand thinning (Table 20). The average weight of the fruitlets thinned by hand were significantly lower for the highest ACC rate (600 $\mu l \cdot L^{-1}$) and the ACC in combination with 6-BA treatment compared to the control and 6-BA (Table 20). The average weight of thinned fruitlets decreased linearly with increasing ACC rate. Slight ACC induced leaf drop was observed in this trial (data not shown). The total yield of trees treated with 200 $\mu l \cdot L^{-1}$ ACC was significantly lower compared to the control and 6-BA, but none of the other treatments differed significantly from the control (Table 21). No significant differences in total yield efficiency were found, but ACC treatments on average decreased yield and seemed to also decrease yield efficiency ($p=0.0538$) compared to the control (Table 21). On average, more fruit was harvested from ACC treated trees than control trees at the first harvest (Table 22). No differences were found at the second harvest dates, but the percentage of fruit harvested during the third harvest from trees treated with the two higher ACC rates was significantly lower than the control and 6-BA (Table 22). None of the treatments had any effect on the overall average fruit weight (Table 22).

Fruit samples from only the second and third harvest dates were analyzed in the laboratory. No significant differences in fruit size (weight, diameter and length) were found (Table 23-24). Fruit shape (ratio of length to diameter) was slightly affected at second harvest, but these differences are of no horticultural significance (Table 23). There was a significant, linear decrease in the average fruit firmness with the increase in ACC rate during the second harvest date and generally the ACC treated trees had less firm fruit than the control trees (Table 25). ACC 600 $\mu l \cdot L^{-1}$ on its own and in combination with 6-BA significantly reduced fruit firmness at both the second and third harvests compared to the control and 6-BA. Split pit incidence ranged from 0 to 7.1% throughout the trial and treatments did not differ significantly (data not shown).

Discussion

'Turquoise'. All ACC treatments reduced the average fruit set and thinning severity increased linearly with increasing application rate. The reduction in fruit set corresponded with the data on the number of fruitlets that had to be thinned by hand during commercial hand thinning. The 6-BA 300 µl.L^{-1} treatment also had a significant thinning effect, which was unexpected since 6-BA was only included in this trial to prevent any phytotoxicity and leaf drop. This thinning effect may be due to 6-BA stimulating the growth of lateral side shoots (Green and Autio, 1992; Elfving and Cline, 1993) increasing the IAA transport out of all the newly released lateral vegetative buds and correlatively inhibiting IAA transport from fruit, thus leading to the abscission of weaker fruitlets (Bangerth, 2000). Exogenously applied Ethephon releases ethylene thereby increasing ethylene levels in plants and stimulating fruit abscission (Wertheim, 1997; 2000). A similar response is expected in response to ACC application. Schupp et al. (2012) found promising results when ACC was used to thin 'Golden Delicious' apple trees. We also reported thinning efficacy of ACC on Japanese plums (Paper 1) and cling peaches (Paper 2). The thinning effect increased linearly with increasing rate of ACC (Schupp et al., 2012; Paper 1; Paper 2). The average fruit size of the hand thinned 'Turquoise' fruitlets was not increased, as was the case in 'African Rose' plums (Paper 1). The severe leaf drop observed in 'Turquoise' is of concern, but Turquoise is known to be a sensitive cultivar and stress symptoms are easily noticeable (H. Laubscher; personal communication).

The highest ACC rate of 500 µl·L^{-1}, alone or in combination with 6-BA, were the only two treatments that significantly lowered total yield and total yield efficiency. The ACC treatments did not advance fruit maturity in this trial, and the two 6-BA treatments delayed fruit maturity as indicated by harvest distribution. Contrary to this, Wünsche et al. (2000) reported that fruit maturity of 'Braeburn'/M.26 apples was advanced on low-cropping trees. No significant effect on fruit size (weight, diameter and length) was found in our trial, which is contrary to what is expected as fruit size normally increases in trees with lower crop loads, but could be due to the leaf drop observed (Costa et al., 1983; Pavel and DeJong, 1993). We found some erratic results regarding fruit firmness at the second and third harvests. At the second harvest there was a quadratic increase in fruit firmness with the inverse effect during the third harvest for the ACC 300 µl·L^{-1} treatment, which was contrary to what we found on

'Keisie' cling peaches where slightly less firm fruit were harvested from the ACC treated trees (Paper 2).

'Alpine'. In general, none of the chemical treatments significantly reduced fruit set on tagged shoots compared to the control, but the two lower ACC rates (200 µl·L^{-1} and 400 µl·L^{-1}), ACC and 6-BA combination, the Darwin 300™ alone and the ACC 400 µl·L^{-1} and Darwin 300™ combination treatment reduced fruit set significantly compared to the flower thinning treatment. Therefore, ACC was not successful in reducing set of 'Alpine' fruitlets at the 8-10 mm diameter stage. This was unexpected in the light of the positive effects seen on 'Turquoise' in the previous season, as well as results on Japanese plums (Paper 1), cling peaches (Paper 2) and 'Golden Delicious' apples (Schupp et al., 2012). With the settings chosen for the Darwin 300™, we expected a similar thinning effect as the full bloom hand flower thinning treatment. Both these treatments resulted in larger fruitlets at commercial hand thinning when compared to the control. De Villiers (2014) also evaluated the Darwin 300™ on various nectarine cultivars with various rotor speeds, viz. 200, 220 and 240 rpm and all treatments significantly reduced the required hand thinning time compared to the control. The benefit of early flower thinning on fruit growth was demonstrated by Grossman and DeJong (1995) on peach trees. The combination treatments of the Darwin 300™ at full bloom followed by a later ACC application enhanced the thinning efficacy; however, not significantly, but resulted in significantly larger fruitlets at commercial hand thinning compared to the ACC and Darwin 300™ treatments on their own and is in agreement with what we found on 'African Rose™' when we utilized the Darwin 300™ (Paper 1).

As the ACC treatments did not thin effectively, they also did not affect yield and yield efficiency. The two ACC and Darwin 300™ combination treatments reduced the yield and yield efficiency compared to the control, similar to what we found with the ACC 800 µl·L^{-1} and Darwin 300™ combination treatment on 'African Rose™' (Paper 1). The yield and yield efficiency for the Darwin 300™ and flower thinning treatment alone did not differ compared to the control. This agrees with what De Villiers (2014) found on the three nectarine cultivars he evaluated the Darwin 300™ on and also with what we found on 'African Rose™' (Paper 1).

In general, treatments altered harvest distribution, but focusing on the first two harvest dates and the two last harvest dates, the two ACC and Darwin 300™ combination treatments, the Darwin 300™ alone and the flower treatment all advanced the harvest. This is similar to what we found with the ACC and Darwin 300™ combination treatments on 'African Rose™' (Paper 1). The early thinning effect of the Darwin 300™, ACC and Darwin 300™ combination treatment and flower hand thinning treatment resulted in an increase in fruit weight, similar to what Pavel and DeJong (1993) found with lower crop loads (Costa et al., 1983). There was a significant reduction in fruit firmness for the ACC treated trees. The same effect was previously observed in apples and plums where fruit maturity showed a clear response to crop load with advanced maturity on low-cropping trees (Wünsche et al., 2000; Paper 1).

'August Red'. None of the treatments had any effect on reducing fruit set or the required hand thinning during commercial hand thinning. This was contrary to what we expected as mentioned for 'Alpine'. We found erratic results regarding total yield where the lowest ACC rate (200 $\mu l \cdot L^{-1}$) resulted in a significantly lower yield than any of the other treatments; however, none of the treatments reduced total yield efficiency in this trial. Fruit size was not improved in this trial as was expected as thinning was not achieved by the treatments, similar to what we reported on 'African Rose™' when ACC 150 $\mu l \cdot L^{-1}$ and ACC 300 $\mu l \cdot L^{-1}$ did not improve thinning (Paper 1).

Conclusion

The thinning effect we obtained with ACC on 'Alpine' and 'August Red' nectarines was not promising. Although ACC caused a linear decrease in set as the rate increased in 'Turquoise' only the highest rate (500 $\mu l \cdot L^{-1}$) reduced the number of fruitlets that needed to be thinned by hand, but caused a significant reduction in yield. ACC had no thinning effect on 'Alpine' or 'August Red', in fact ACC 400 $\mu l \cdot L^{-1}$ slightly increased fruit set in the case of 'Alpine'. The Darwin 300™ showed promise as a mechanical thinning option on nectarines as found earlier (De Villiers, 2014; Theron et al., 2015) when the required hand thinning was reduced by approximately 60% compared to the control, without having an effect on yield. ACC would not be recommended for thinning of nectarines at this stage and further studies are needed. The reason for the lack of an effect of ACC on nectarines compared to the very promising results obtained on Japanese plums and peaches is uncertain.

Literature cited

ARC Infruitec-Nietvoorbij, 2014. http:// 155.240.161.9/ systems/ ecommerce/ shoppingall/ cultivars/ searchresult.php

Bangerth, F. 2000. Abscission and thinning of young fruit and their regulation by plant hormones and bioregulators. Plant Growth Regul. 31(1):43–59. Available at: http://dx.doi.org/10.1023/A:1006398513703.

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

Coetzee, J. and K. Theron. 1999a. Efficacy of Armothin as a chemical thinner applied during different flowering stages of 'Sunlite' nectarines. J. of SA. Soc. Hort. Sci. 9(1):8-12.

Coetzee, J. and K. Theron. 1999b. The effect of Ralex® on fruit firmness and storage ability in the season of application and on bud density, yield and fruit size in the season following application in 'Sunlite' nectarines. J. of SA. Soc. Hort. Sci. 9(1):13-17.

Costa, G., C. Giulivo, and A. Ramina. 1983. Effects of the different flower/vegetative buds ratio on the peach fruit abscission and growth. Acta Hort. (139):149–160.

Day, K.R. and T.M. DeJong. 1998. Improving fruit size: Thinning and girdling nectarines, peaches, and plums. The Compact Fruit Tree 32(2):1–6.

De Villiers, M.H.J. 2014. Mechanical and chemical thinning of stone fruit. MScAgric thesis, Stellenbosch University.

Elfving, D.C. and RA Cline. 1993. Benzyladenine and other chemicals for thinning Empire apple trees. J. Amer. Soc. Hort. Sci. 118:593–598.

Fallahi, E. 1997. Applications of endothalic acid, pelagronis acid, and hydrogen cyanamide for blossom thinning in apple and peach. Hortechnology 7(4):395–399.

Gonzalez-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. Autio, 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. DeJong. 1995. Maximum fruit growth potential and seasonal patterns of resource dynamics during peach growth. Ann. Bot-London 75:553–560.

HORTGRO. 2014. http://www.hortgro.co.za/market-intelligence-statistics/key-deciduous-fruit-statistics/

Martín, 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.

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(1):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.

Nyéki, J., Z. Szabó, A. Andrásfalvy, M. Soltész, and J. Kovács. 1998. Open pollination and autogamy of peach and nectarine varieties. Acta Hort. 465:279-284. (abstr.).

Pavel, E. and T. DeJong. 1993. Source-and sink-limited growth periods of developing peach fruits indicated by relative growth rate analysis. J. Amer. Soc. Hort. Sci. 118(6):820–824.

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(9):1308-1311.

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.

Webster, A. and J. Spencer. 2000. Fruit thinning plums and apricots. Plant Growth Regul. 31(1-2):101-112.

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 Regul. 31:85-100.

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(1):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-l-carboxylic acid (ACC) and ACC synthase. Plant Cell Physiol. 22(3):369–379 (abstr.).

Table 1. Treatment specifications for trials done with 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on 'Turquoise' nectarines in the season of 2013/2014

Treatments
Untreated control
6-benzyladenine (6-BA) (100 µl·L^{-1}) at 8-10 mm fruit diameter*
6-benzyladenine (6-BA)(300 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (150 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (300 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (500 µl·L^{-1}) at 8-10 mm fruit diameter*
6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1}) at 8 -10 mm fruit diameter*

* Actual average fruitlet diameter at application was 7-14 mm

Table 2. Summary of the dates of treatment application, follow up hand thinning of fruitlets and harvest for 'Turquoise' nectarines in the season of 2013/2014.

Phenological stage	Date
Chemical application	10 Oct. 2013
Follow-up hand thinning of fruitlets	24 Oct. 2013
Harvest dates	4, 6, 9 and 11 Dec. 2013

Table 3. Treatment specifications for trials done with 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and the Darwin mechanical thinner on 'Alpine' nectarines in the season of 2014/2015.

Treatments
Untreated control
Darwin 300™ at full bloom
Flower thinning
6-benzyladenine (6-BA) (100 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (200 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (400 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (600 µl·L^{-1}) at 8-10 mm fruit diameter*
6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1}) at 8-10 mm fruit diameter*
Darwin at full bloom + ACC (400 µl·L^{-1}) at 8-10 mm Fruit diameter*
Darwin at full bloom + ACC (600 µl·L^{-1}) at 8-10 mm Fruit diameter*

* Actual average fruitlet diameter at application was 7.55 mm

Table 4. Summary of the dates of treatment application, follow up hand thinning of fruitlets and harvest for 'Alpine' nectarines in the season of 2014/2015.

Phenological stage	6-BA, ACC, hand thinning and mechanical thinning
	Alpine
Mechanical thinning with Darwin	7 July 2014
Flower thinning	7 July 2014
Chemical application	15 Aug. 2014
Follow-up hand thinning of fruitlets	9 Sept. 2014
Harvest dates	30 Oct., 4, 7, 10, 11, 17, 19, 24 Nov. 2014

Table 5. Treatment specifications for trials done with 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on 'August Red' nectarines in the season of 2014/2015

Treatments
Untreated control (UTC)
6-BA (100 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (200 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (400 µl·L^{-1}) at 8-10 mm fruit diameter*
ACC (600 µl·L^{-1}) at 8-10 mm fruit diameter*
6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1}) at 8-10 mm fruit diameter*

* Actual average fruitlet diameter at application was 7.85 mm

Table 6. Summary of the dates of treatment application, follow up hand thinning of fruitlets and harvest for 'August Red' nectarines in the season of 2014/2015.

Phenological stage	August Red
Chemical application	22 Sept. 2014
Follow-up hand thinning of fruitlets	20 Oct. 2014
Harvest dates	3, 10, 16 Feb. 2015

Table 7. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit set and thinning required in 'Turquoise' nectarine at Vreeland, Ceres, South Africa (2013/2014).

Treatment	Average fruit set on 8 1-yr-old shoots	Average number of fruitlets thinned by hand	Average weight of hand thinned fruitlets (g)	Score of leaf drop**
Control	88.7 a	648 ab	2.2 abc	1.38 e
6-BA 100	89.7 a	705 a	2.3 abc	1.00 f
6-BA 300	84.0 b	648 ab	2.2 abc	1.00 f
ACC 150	75.0 b	603 ab	2.5 a	2.75 d
ACC 300	71.1 c	544 bc	2.3 ab	4.13 b
ACC 500	53.2 c	482 cd	2.1 bc	5.00 a
6-BA + ACC*	57.0 c	438 d	2.0 c	3.63 c
Significance level	*<0.0001*	*<0.0001*	*0.0396*	*<0.0001*
LSD 5%	*7.98*	*105.05*	*0.26*	*0.37*
BA vs. ACC	*<0.0001*	*0.0003*	*0.6951*	*<0.0001*
ACC Linear	*<0.0001*	*0.0257*	*0.0083*	*<0.0001*
ACC Quadratic	*0.1211*	*0.8768*	*0.8784*	*0.0141*
Control vs. Rest	*<0.0001*	*0.0562*	*0.8147*	*<0.0001*

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})
** Leaf drop scored from 1 – 5, with 1 no drop and 5 very severe drop (see Fig. 1).

Table 8. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on yield and yield efficiency in 'Turquoise' nectarine at Vreeland, Ceres, South Africa (2013/2014).

Treatment	Total yield per tree (kg)	Estimated yield per hectare (ton)	Total yield efficiency (kg·cm^{-2})
Control	16.2 a	27.0	0.30 a
6-BA 100	15.9 ab	26.5	0.31 a
6-BA 300	16.2 a	26.9	0.28 a
ACC 150	15.9 ab	26.5	0.30 a
ACC 300	15.6 ab	26.0	0.27 a
ACC 500	13.0 bc	21.6	0.21 b
6-BA + ACC*	12.0 c	20.0	0.22 b
Significance level	*0.0328*	-	*0.0003*
LSD 5%	*3.07*	-	*0.05*
BA vs. ACC	*0.2222*	-	*0.0359*
ACC Linear	*0.0512*	-	*0.0004*
ACC Quadratic	*0.4821*	-	*0.4808*
Control vs. Rest	*0.2236*	-	*0.0616*

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 9. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on yield efficiency in 'Turquoise' nectarine at Vreeland, Ceres, South Africa (2013/2014).

Treatment	Yield efficiency first harvest ($kg \cdot cm^{-2}$)		Yield efficiency second harvest ($kg \cdot cm^{-2}$)		Yield efficiency third harvest ($kg \cdot cm^{-2}$)		Yield efficiency fourth harvest ($kg \cdot cm^{-2}$)	
Control	0.13	ab	0.08	ns	0.08	ns	0.01	b
6-BA 100	0.16	a	0.07		0.05		0.03	a
6-BA 300	0.10	bc	0.07		0.06		0.04	a
ACC 150	0.15	a	0.07		0.06		0.01	b
ACC 300	0.10	bc	0.10		0.06		0.01	b
ACC 500	0.09	c	0.07		0.04		0.01	b
6-BA + ACC*	0.09	bc	0.07		0.05		0.01	b
Significance level	*0.0020*		*0.4059*		*0.4916*		*<0.0001*	
LSD 5%	*0.04*		-		-		*0.01*	
BA vs. ACC	*0.1809*		*0.2150*		*0.8290*		*<0.0001*	
ACC Linear	*0.0031*		*0.9919*		*0.2725*		*0.1858*	
ACC Quadratic	*0.1917*		*0.0416*		*0.6760*		*0.8573*	
Control vs. Rest	*0.3532*		*0.8223*		*0.0686*		*0.1752*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (500 $\mu l \cdot L^{-1}$)

Table 10. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on harvest distribution and fruit weight in 'Turquoise' nectarine at Vreeland, Ceres, South Africa (2013/2014).

Treatment	Percentage of fruit picked at first harvest		Percentage of fruit picked at second harvest		Percentage of fruit picked at third harvest		Percentage of fruit picked at fourth harvest		Average weight of fruit (g)	
Control	38.6	ns	26.8	ns	27.6	ns	7.0	b	101.3	ns
6-BA 100	47.9		20.9		16.5		14.7	a	102.7	
6-BA 300	34.2		24.8		22.7		18.3	a	105.7	
ACC 150	47.5		24.0		21.1		7.3	b	103.4	
ACC 300	35.4		36.8		22.0		5.8	b	105.2	
ACC 500	37.7		36.6		22.3		3.4	b	102.0	
6-BA + ACC*	39.8		32.7		23.0		4.5	b	107.5	
Significance level	*0.4127*		*0.0685*		*0.5976*		*<0.0001*		*0.3976*	
LSD 5%	-		-		-		*5.03*		-	
BA vs. ACC	*0.8633*		*0.0200*		*0.5223*		*<0.0001*		*0.7308*	
ACC Linear	*0.2394*		*0.0607*		*0.8310*		*0.1168*		*0.5891*	
ACC Quadratic	*0.2347*		*0.1757*		*0.9392*		*0.9270*		*0.3848*	
Control vs. Rest	*0.7590*		*0.5993*		*0.1235*		*0.2926*		*0.1841*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (500 $\mu l \cdot L^{-1}$)

Table 11. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at first harvest in 'Turquoise' nectarine at Vreeland, Ceres, South Africa (2013/2014).

Treatment	Average fruit weight at first harvest (g)		Average fruit diameter at first harvest (mm		Average fruit length at first harvest (mm)		Average fruit length to diameter ratio at first harvest	
Control	113.3	ns	58.3	ns	59.5	ns	1.02	ns
6-BA 100	114.2		58.6		59.8		1.02	
6-BA 300	117.8		58.8		60.2		1.02	
ACC 150	114.6		58.8		59.7		1.02	
ACC 300	116.9		58.8		60.1		1.02	
ACC 500	112.5		58.3		58.9		1.01	
6-BA + ACC*	118.6		59.1		60.3		1.02	
Significance level	*0.6176*		*0.7625*		*0.4429*		*0.5619*	
LSD 5%	-		-		-		-	
BA vs. ACC	*0.5905*		*0.8440*		*0.3812*		*0.2140*	
ACC Linear	*0.5219*		*0.3517*		*0.2336*		*0.4528*	
ACC Quadratic	*0.3480*		*0.5905*		*0.2008*		*0.1469*	
Control vs. Rest	*0.3996*		*0.3392*		*0.5575*		*0.7019*	

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 12. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at second harvest in 'Turquoise' nectarine at Vreeland, Ceres, South Africa (2013/2014).

Treatment	Average weight of fruit at second harvest (g)		Average fruit diameter at second harvest (mm)		Average fruit length at second harvest (mm)		Average fruit length to diameter ratio at second harvest	
Control	102.4	ns	56.1	ns	57.9	ns	1.03	ab
6-BA 100	102.8		55.9		57.8		1.03	a
6-BA 300	105.8		56.6		58.0		1.02	abc
ACC 150	91.4		56.0		57.2		1.02	bc
ACC 300	102.5		55.7		57.7		1.04	a
ACC 500	98.8		54.6		56.0		1.03	abc
6-BA + ACC*	104.1		55.5		56.5		1.02	c
Significance level	*0.6081*		*0.2816*		*0.1219*		*0.0487*	
LSD 5%	-		-		-		*0.01*	
BA vs. ACC	*0.1864*		*0.1101*		*0.0787*		*0.6295*	
ACC Linear	*0.3946*		*0.0682*		*0.1263*		*0.5310*	
ACC Quadratic	*0.2481*		*0.6359*		*0.1605*		*0.0295*	
Control vs. Rest	*0.7987*		*0.5723*		*0.2661*		*0.2048*	

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 13. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at third harvest in ‘Turquoise’ nectarine at Vreeland, Ceres, South Africa (2013/2014).

Treatment	Average weight of fruit at third harvest (g)	Average fruit diameter at third harvest (mm)	Average fruit length at third harvest (mm)	Average fruit length to diameter ratio at third harvest
Control	93.2 ns	55.8 ns	56.3 ns	1.01 ns
6-BA 100	97.8	55.6	55.5	0.99
6-BA 300	102.5	57.0	56.9	0.99
ACC 150	96.4	55.5	56.3	1.01
ACC 300	97.7	56.2	56.5	1.00
ACC 500	91.6	54.9	55.3	1.01
6-BA + ACC*	99.1	55.9	56.7	1.01
Significance level	*0.1379*	*0.2717*	*0.3653*	*0.3717*
LSD 5%	-	-	-	-
BA vs. ACC	*0.0584*	*0.1574*	*0.7101*	*0.0719*
ACC Linear	*0.2002*	*0.4303*	*0.1784*	*0.3580*
ACC Quadratic	*0.3279*	*0.1699*	*0.3807*	*0.3770*
Control vs. Rest	*0.1543*	*0.9699*	*0.9147*	*0.7819*

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 14. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit firmness in ‘Turquoise nectarine at Vreeland, Ceres, South Africa (2013/2014).

Treatment	Average fruit firmness at first harvest (kg)	Average fruit firmness at second harvest (kg)	Average fruit firmness at third harvest (kg)
Control	10.5 ns	10.1 c	10.6 bc
6-BA 100	10.4	10.8 bc	10.3 c
6-BA 300	10.6	10.6 bc	11.3 ab
ACC 150	10.7	10.4 bc	11.2 abc
ACC 300	10.9	11.6 a	10.6 bc
ACC 500	11.1	11.6 a	11.6 a
6-BA + ACC*	11.1	11.0 ab	11.6 a
Significance level	*0.4760*	*0.0013*	*0.0187*
LSD 5%	-	*0.80*	*0.86*
BA vs. ACC	*0.1501*	*0.0496*	*0.3224*
ACC Linear	*0.3611*	*0.0055*	*0.2670*
ACC Quadratic	*0.9677*	*0.0380*	*0.0490*
Control vs. Rest	*0.4397*	*0.0036*	*0.1323*

* 6-BA (100 µl·L^{-1}) + ACC (500 µl·L^{-1})

Table 15. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit set and thinning required in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South Africa (2014/2015).

Treatment	Average fruit set on 5 1-yr-old shoots		Average fruit set on 5 1-yr-old shoots (Flower thinning treatments)		Average number of fruitlets thinned by hand		Average weight of hand thinned fruitlets (g)	
Control	71.0	abc	65.3	a	1165	b	7.9	bc
Darwin at full bloom	68.4	bc	27.2	c	454	cd	9.5	a
Flower thinning	76.7	a	39.8	b	609	c	9.2	a
6-BA 100	72.0	abc	-	-	1070	b	7.9	b
ACC 200	66.1	c	-	-	1159	b	7.8	bcd
ACC 400	65.8	c	-	-	1394	a	7.2	cd
ACC 600	71.3	abc	-	-	1235	ab	7.1	d
6-BA + ACC*	67.2	c	-	-	1067	b	7.3	bcd
Darwin + ACC 400	66.2	c	24.9	c	394	cd	9.6	a
Darwin + ACC 600	74.7	ab	27.1	c	358	d	9.5	a
Significance level	*0.0261*		*<0.0001*		*<0.0001*		*<0.0001*	
LSD 5%	*7.17*		*5.61*		*222.77*		*0.75*	
ACC vs. ACC + Darwin	*0.4590*		-		*<0.0001*		*<0.0001*	
ACC Linear	*0.1541*		-		*0.5009*		*0.0601*	
ACC Quadratic	*0.3598*		-		*0.0456*		*0.4174*	
Control vs. Rest	*0.6573*		-		*0.0005*		*0.0954*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 16. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on yield, yield efficiency and fruit weight in 'Alpine' nectarine, at Swartdam, Riebeek Kasteel, South Africa (2014/2015).

Treatment	Total yield per tree (kg)		Estimated yield per hectare (ton)	Total yield efficiency ($kg \cdot cm^{-2}$)		Average weight of fruit (g)	
Control	34.7	ab	43.4	0.46	abc	119.7	cd
Darwin at full bloom	29.5	bcd	36.8	0.40	cde	129.4	a
Flower thinning	35.3	ab	44.1	0.50	ab	126.2	ab
6-BA 100	32.2	bc	40.2	0.45	abcd	122.3	bc
ACC 200	30.8	bcd	38.5	0.44	bcde	118.3	cd
ACC 400	40.0	a	50.0	0.53	a	118.1	cd
ACC 600	32.1	bc	40.2	0.45	bcd	116.4	d
6-BA + ACC*	30.6	bcd	38.3	0.44	bcd	118.5	cd
Darwin + ACC 400	27.1	cd	33.9	0.37	de	130.1	a
Darwin + ACC 600	25.5	d	31.9	0.36	e	130.9	a
Significance level	*0.0010*		-	*0.0019*		*<0.0001*	
LSD 5%	*6.28*		-	*0.08*		*4.94*	
ACC vs. ACC + Darwin	*<0.0001*		-	*<0.0001*		*<0.0001*	
ACC Linear	*0.6628*		-	*0.8889*		*0.4278*	
ACC Quadratic	*0.0025*		-	*0.0193*		*0.7213*	
Control vs. Rest	*0.1714*		-	*0.5158*		*0.0495*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$)

Table 17. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on harvest distribution in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, 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		Percentage of fruit picked at fourth harvest	
Control	1.7	bcd	5.1	c	6.6	bcde	12.1	d
Darwin at full bloom	3.7	a	17.3	a	10.8	a	23.7	a
Flower thinning	2.2	abc	11.7	b	8.1	abcd	20.1	abc
6-BA 100	1.3	bcd	5.9	c	5.0	de	17.3	abcd
ACC 200	2.0	abcd	7.3	c	8.7	abc	20.8	abc
ACC 400	0.1	d	5.1	c	4.1	e	16.8	bcd
ACC 600	0.5	cd	4.3	c	5.5	bcde	15.6	cd
6-BA + ACC*	1.6	bcd	5.6	c	5.2	cde	19.6	abc
Darwin + ACC 400	3.2	ab	18.9	a	9.0	ab	22.8	ab
Darwin + ACC 600	3.1	ab	16.6	a	7.8	abcd	23.1	ab
Significance level	*0.0116*		*<0.0001*		*0.0065*		*0.0109*	
LSD 5%	*2.038*		*4.2545*		*3.5602*		*6.4974*	
ACC vs. ACC + Darwin	*0.0002*		*<0.0001*		*0.0061*		*0.0046*	
ACC Linear	*0.1473*		*0.1571*		*0.0756*		*0.1159*	
ACC Quadratic	*0.2301*		*0.7120*		*0.0584*		*0.6439*	
Control vs. Rest	*0.7166*		*0.0018*		*0.7106*		*0.0018*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$)

Table 18. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on harvest distribution in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Percentage of fruit picked at fifth harvest		Percentage of fruit picked at sixth harvest		Percentage of fruit picked at seventh harvest		Percentage of fruit picked at eighth harvest	
Control	17.8	ns	15.1	ab	10.1	abc	31.4	a
Darwin at full bloom	12.8		9.0	c	7.5	cde	15.1	c
Flower thinning	15.6		14.6	ab	9.1	bcd	18.6	bc
6-BA 100	14.9		14.2	abc	11.3	ab	30.1	a
ACC 200	12.0		12.2	bc	9.1	bcd	27.9	ab
ACC 400	14.2		15.9	ab	10.4	abc	33.3	a
ACC 600	12.3		19.2	a	12.6	a	30.2	a
6-BA + ACC*	12.8		17.0	ab	7.9	cde	30.3	a
Darwin + ACC 400	13.4		12.9	bc	6.0	e	14.0	c
Darwin + ACC 600	11.4		16.0	ab	6.8	de	15.3	c
Significance level	*0.3681*		*0.0316*		*0.0010*		*<0.0001*	
LSD 5%	-		*5.33*		*3.12*		*10.48*	
ACC vs. ACC + Darwin	*0.6527*		*0.1076*		*<0.0001*		*<0.0001*	
ACC Linear	*0.9292*		*0.0114*		*0.0292*		*0.6622*	
ACC Quadratic	*0.3601*		*0.9427*		*0.7610*		*0.3595*	
Control vs. Rest	*0.0224*		*0.7985*		*0.3237*		*0.0574*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 19. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit size and shape in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Average fruit diameter (mm)		Average fruit length (mm)		Average fruit length to diameter ratio		Average fruit firmness (kg)	
Control	62.2	cd	55.9	bc	0.90	ab	10.1	abc
Darwin at full bloom	63.9	a	57.7	a	0.90	a	10.6	a
Flower thinning	63.3	ab	57.3	a	0.90	a	10.7	a
6-BA 100	62.6	bc	56.2	b	0.90	ab	10.2	ab
ACC 200	61.9	cd	55.3	cd	0.89	bc	9.5	bcd
ACC 400	61.8	cd	55.1	cd	0.89	bc	9.3	d
ACC 600	61.4	d	54.6	d	0.89	c	8.9	d
6-BA + ACC*	61.7	d	55.2	cd	0.89	bc	9.4	cd
Darwin + ACC 400	63.9	a	57.3	a	0.90	bc	10.1	abc
Darwin + ACC 600	63.9	a	57.1	a	0.89	bc	9.4	d
Significance level	*<0.0001*		*<0.0001*		*0.0009*		*<0.0001*	
LSD 5%	*0.86*		*0.88*		*0.01*		*0.73*	
ACC vs. ACC + Darwin	*<.0001*		*<0.0001*		*0.1494*		*0.0211*	
ACC Linear	*0.2105*		*0.1084*		*0.3172*		*0.0994*	
ACC Quadratic	*0.7716*		*0.7118*		*0.8206*		*0.7497*	
Control vs. Rest	*0.0855*		*0.3320*		*0.2803*		*0.2321*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$)

Table 20. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit set and thinning required in 'August Red' nectarine at Bo-Bokfontein, Koue Bokkeveld, South Africa (2014/2015).

Treatment	Average fruit set on 5 1-yr-old shoots		Average number of fruitlets thinned by hand		Average weight of hand thinned fruitlets (g)	
Control	72.6	ns	1099	ns	7.7	a
6-BA 100	71.1		1343		7.5	a
ACC 200	70.2		1089		7.2	ab
ACC 400	70.6		1066		7.3	ab
ACC 600	66.8		1260		6.4	c
6-BA + ACC*	62.2		1137		6.9	bc
Significance level	*0.0516*		*0.2649*		*0.0012*	
LSD 5%	-		-		*0.57*	
Control vs. ACC	*0.0679*		*0.7181*		*0.0035*	
ACC Linear	*0.3268*		*0.2116*		*0.0078*	
ACC Quadratic	*0.4817*		*0.3602*		*0.0705*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 21. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on yield and yield efficiency in 'August Red' nectarine at Bo-Bokfontein, Koue Bokkeveld, South Africa (2014/2015).

Treatment	Yield (kg/tree)		Estimated tons per ha	Yield efficiency (kg.cm^{-2})	
Control	51.4	ab	85.6	1.00	ns
6-BA 100	57.3	a	95.5	1.05	
ACC 200	42.3	c	70.5	0.89	
ACC 400	44.7	bc	74.5	0.83	
ACC 600	47.4	bc	78.9	0.78	
6-BA + ACC*	44.1	bc	73.5	0.89	
Significance level	*0.0015*		-	*0.0870*	
LSD 5%	*7.33*		-	-	
Control vs. ACC	*0.0235*		-	*0.0538*	
ACC Linear	*0.1686*		-	*0.3130*	
ACC Quadratic	*0.9723*		-	*0.9745*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 22. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on harvest distribution and fruit weight in 'August Red' nectarine at Bo-Bokfontein, Koue Bokkeveld, 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		Average weight of fruit (g)	
Control	4.8	ns	20.8	ns	74.4	ab	172.8	ns
6-BA 100	7.8		16.8		75.4	a	175.2	
ACC 200	9.9		22.4		67.7	abc	179.7	
ACC 400	11.0		24.9		64.1	c	176.2	
ACC 600	11.7		23.6		64.7	c	181.5	
6-BA + ACC*	10.5		22.8		66.7	bc	180.2	
Significance level	*0.2204*		*0.2591*		*0.0292*		*0.6313*	
LSD 5%	-		-		*8.35*		-	
Control vs. ACC	*0.0153*		*0.3452*		*0.0123*		*0.1519*	
ACC Linear	*0.5496*		*0.7235*		*0.4688*		*0.7531*	
ACC Quadratic	*0.9412*		*0.5162*		*0.5528*		*0.3790*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 23. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at the second harvest in 'August Red' nectarine at Bo-Bokfontein, Koue Bokkeveld, South Africa (2014/2015).

Treatment	Average weight of fruit for second harvest (g)		Average fruit diameter at second harvest (mm)		Average fruit length at second harvest (mm)		Average fruit length to diameter ratio at second harvest	
Control	183.0	ns	69.2	ns	66.9	ns	0.97	a
6-BA 100	184.2		68.9		66.3		0.96	a
ACC 200	192.2		69.7		66.9		0.96	ab
ACC 400	186.0		69.6		66.2		0.95	bc
ACC 600	190.7		70.1		66.4		0.95	c
6-BA + ACC*	185.9		68.7		66.3		0.97	a
Significance level	*0.6269*		*0.4752*		*0.7774*		*0.0009*	
LSD 5%	-		-		-		*0.01*	
Control vs. ACC	*0.2494*		*0.6255*		*0.3732*		*0.0078*	
ACC Linear	*0.8121*		*0.5842*		*0.4112*		*0.0091*	
ACC Quadratic	*0.3105*		*0.6425*		*0.4641*		*0.6833*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 24. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit size and shape at the third harvest in 'August Red' nectarine at Bo-Bokfontein, Koue Bokkeveld, South Africa (2014/2015).

Treatment	Average weight of fruit for third harvest (g)		Average fruit diameter at third harvest (mm)		Average fruit length at third harvest (mm)		Average fruit length to diameter ratio at third harvest	
Control	162.5	ns	65.8	ns	65.0	ns	0.98	ns
6-BA 100	166.3		66.0		65.4		0.99	
ACC 200	167.2		66.2		64.9		0.98	
ACC 400	166.4		66.5		65.2		0.98	
ACC 600	172.3		65.9		64.8		0.98	
6-BA + ACC*	174.4		66.8		65.3		0.98	
Significance level	*0.6473*		*0.8517*		*0.9770*		*0.1284*	
LSD 5%	-		-		-		-	
Control vs. ACC	*0.2119*		*0.4808*		*0.9756*		*0.1027*	
ACC Linear	*0.5014*		*0.7401*		*0.9011*		*0.5984*	
ACC Quadratic	*0.6091*		*0.5513*		*0.6254*		*0.7375*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 25. Effect of 6-benzyladenine (6-BA) and 1-aminocyclopropane carboxylic acid (ACC) on fruit firmness in 'August Red' nectarine at Bo-Bokfontein, Koue Bokkeveld, South Africa (2014/2015).

Treatment	Average fruit firmness at second harvest (kg)		Average fruit firmness at third harvest (kg)	
Control	10.2	a	8.0	a
6-BA 100	9.7	a	8.0	a
ACC 200	9.5	a	7.1	ab
ACC 400	8.5	b	7.4	ab
ACC 600	8.2	b	6.3	b
6-BA + ACC*	8.4	b	5.9	b
Significance level	*0.0007*		*0.0328*	
LSD 5%	*1.00*		*1.52*	
Control vs. ACC	*0.0004*		*0.0248*	
ACC Linear	*0.0129*		*0.2936*	
ACC Quadratic	*0.3597*		*0.3098*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

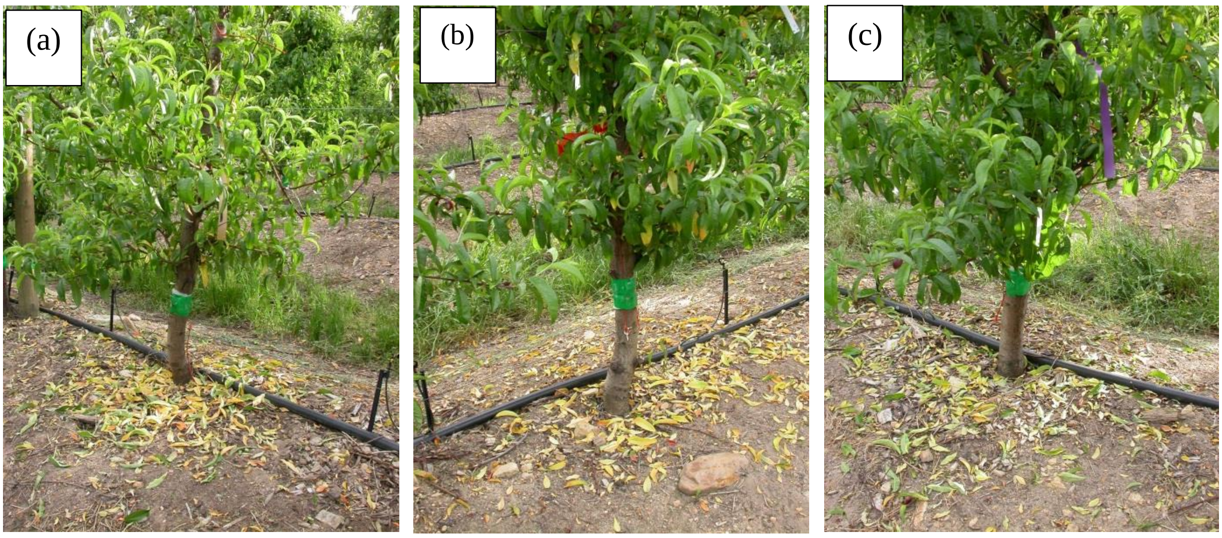

Fig 1. Effect of different chemical thinning applications on leaf drop observed under 'Turquoise' trees at Vreeland, Warm Bokkeveld in the 2014/15 season. (a) ACC 500 µl·L^{-1}, (b) ACC 300 µl·L^{-1}, (c) ACC 500 µl·L^{-1} + 6-BA 100 µl·L^{-1}.

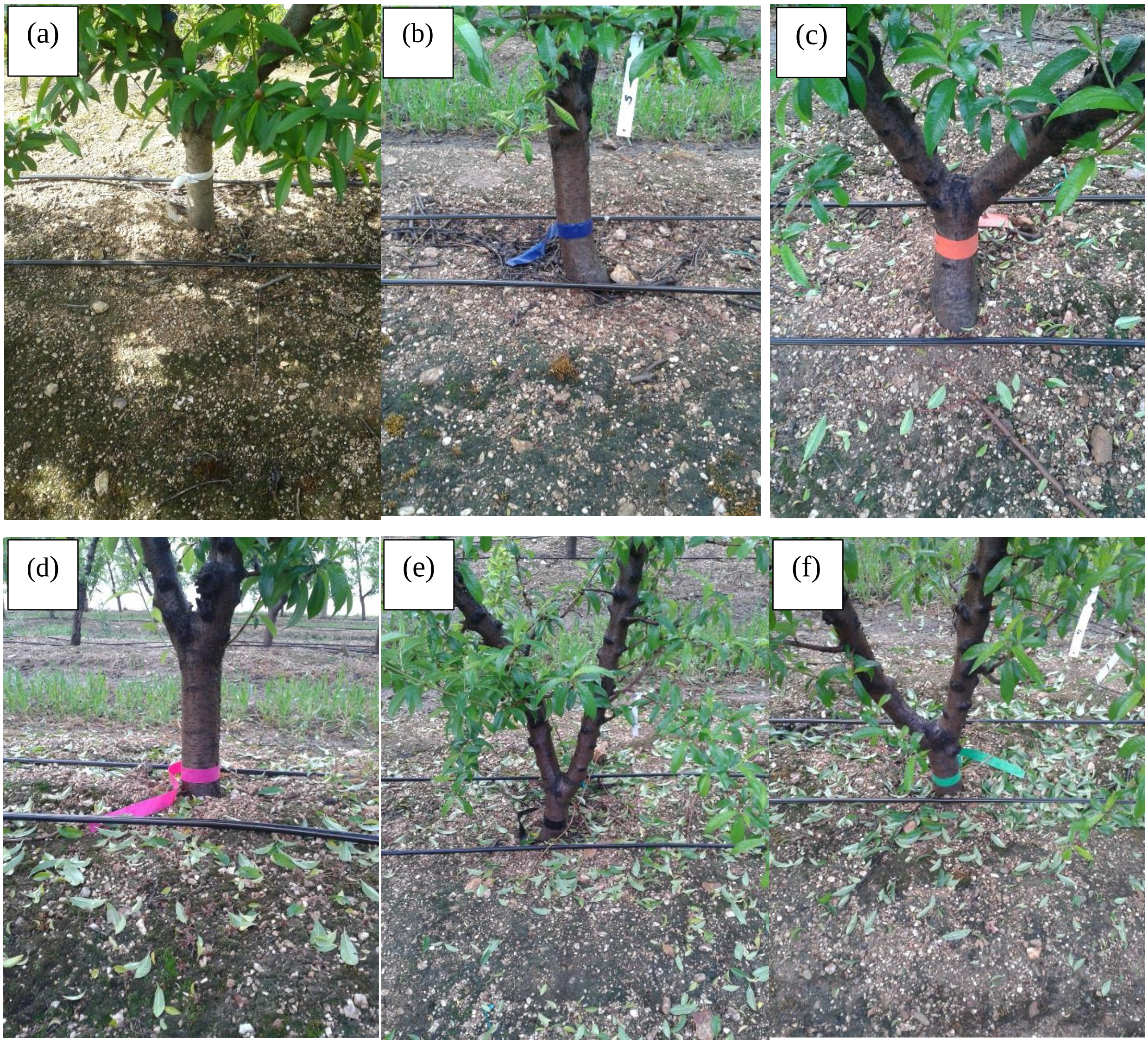

Fig 2. Effect of different chemical thinning applications on leaf drop observed under 'Alpine' trees at Swartdam, Riebeek Kasteel in the 2014/15 season. (a) untreated control, (b) 6-BA 100 µl·L^{-1}, (c) ACC 200 µl·L^{-1}, (d) ACC 400 µl·L^{-1}, (e) ACC 600 µl·L^{-1} and (f) ACC 600 µl·L^{-1} + 6-BA 100 µl·L^{-1}.

GENERAL DISCUSSION AND CONCLUSION

Natural abscission of fruit is not sufficient to reduce crop load to the correct commercial level and thinning of stone fruit, whether by hand, chemically or mechanically, is needed. The cost of hand thinning is the driving force behind the development of new thinning techniques (Pela, 2015). Therefore, alternatives like chemical or mechanical thinning have to be considered to reduce production costs.

We found promising thinning results with ACC and 6-BA on Japanese plums. This is similar to what Meland and Birken (2010) found with Ethephon on 'Victoria' plums. During both seasons the benefit of early thinning of 'African Rose™' was demonstrated in that the average fruit size of the hand thinned fruitlets was already larger at the time of hand thinning compared to the control. This benefit of early flower thinning on fruit growth was also demonstrated by Grossman and DeJong (1995) on peach trees, therefore the combination treatment of the Darwin 300™ at full bloom followed by a later ACC application is recommended for a heavy setting, self-fertile cultivar like African Rose™. The benefit of thinning with the Darwin 300™ and ACC was also seen in fruit size and yield in 'African Rose™'. The combination treatments between the Darwin 300™ and ACC advanced harvest and almost 30% more fruit was picked at the first harvest date, potentially reducing the number of times the orchard needs picking and therefore further reducing labor cost. We concluded that for a self-fertile cultivar like African Rose™ ACC at 600 $\mu l \cdot L^{-1}$ should be used and possibly also combined with mechanical flower thinning.

ACC successfully thinned 'Laetitia'. Interestingly the combination treatment between ACC and 6-BA had an even bigger thinning effect than the same ACC rate (600 $\mu l \cdot L^{-1}$) alone, which we ascribe to the fact that this particular 'Laetitia' orchard was relatively young and 6-BA may have stimulated the growth of lateral side shoots (Green and Autio, 1992; Elfving and Cline, 1993). The data indicated that the recommended rate for this relatively young and vigorous 'Laetitia' orchard should be 400 $\mu l.L^{-1}$. It could be that a more mature, and less vigorous orchard with high set potential might require a higher rate of ACC. We were less successful in establishing what the recommended ACC rate would be for 'Fortune'. Thinning was achieved with 400 and 600 $\mu l \cdot L^{-1}$ ACC, but it would appear that these treatments over thinned, indicated by the significant reduction in yield. Therefore 'Fortune' is more sensitive to ACC than 'African Rose™' and the recommended ACC rate would be between 200 and 400 $\mu l \cdot L^{-1}$. Generally the 6-BA treatment did not have a thinning effect, which was expected

(S. Reynolds, personal communication). From the pilot trial we did in 2013/2014 on 'Laetitia', we concluded that ACC should not be applied at temperatures exceeding 30 °C which could result in phytotoxicity and leaf drop. Applications should be made early morning or during the evening at lower temperatures as no leaf drop was observed under such conditions in the three cultivars evaluated.

In our studies on cling peaches, we found similar and promising results with ACC, especially on 'Keisie'. ACC did reduce fruit set linearly as the ACC rate increased, similarly to the effect observed in 'Golden Delicious' apples (Schupp et al., 2012) and Japanese plums (Paper 1). No reduction in yield was observed in both seasons and fruit size was not affected. The recommended rate to thin 'Keisie' would be 600 $\mu l \cdot L^{-1}$ ACC. In 'Sandvliet' over thinning occurred at the rates used on 'Keisie', indicating that the rates of ACC were too high for this more sensitive cultivar, as also indicated by more severe leaf drop. Another possibility might be that a delayed thinning effect was induced by ACC. Even though we observed a significant increase in fruit size it did not compensate for the reduction in yield (Njoroge and Reighard, 2008). Further research is needed to determine optimum ACC concentrations for different cling peach cultivars.

The thinning efficacy of ACC on nectarines was disappointing. Turquoise was the only cultivar that responded to a certain extent to ACC and the ACC treatments reduced the average fruit set linearly with the increasing rate. However the two most important nectarine cultivars in South Africa, Alpine and August Red were not effectively thinned by ACC and some phytotoxicity was observed. The Darwin 300™ utilized on 'Alpine' showed promise as a mechanical thinning option on nectarines as found earlier (De Villiers, 2014; Theron et al., 2015). ACC would therefore not be recommended for thinning of nectarines at this stage and further studies are needed.

Conclusion

During the course of two seasons we did find promising results regarding the efficacy of ACC on stone fruit as a chemical thinner. The differences we found between Japanese plums, cling peaches and nectarines is still somewhat of a mystery. Initially it was thought that plums responded best as fruit set in clusters vs. the single fruit setting on peaches and nectarines, but this would have meant a similar response between peach and nectarine. It could be related to the different bearing habits, leaf structure, or different phenological stages sensitive to ACC application. This research sets the base-line for future studies with ACC and the possibility of ACC and the Darwin 300™ in combination or on their own to become more cost effective thinning options to hand thinning alone in the future.

Literature cited

De Villiers, M.H.J. 2014. Mechanical and chemical thinning of stone fruit. MScAgric thesis, Stellenbosch University.

Elfving D.C. and RA Cline. 1993. Benzyladenine and other chemicals for thinning Empire apple trees. J. Amer. Soc. Hort. Sci. 118:593–598.

Green D.W., W.R. Autio, 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. DeJong. 1995. Maximum fruit growth potential and seasonal patterns of resource dynamics during peach growth. Ann. Bot-London 75:553–560.

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.

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.

Pela, M. Department of Labour. 2015/2016. Labour Minister Oliphant increases farmworkers minimum wage by 7.7 percent in 2015/16. <http://www.labour.gov.za/DOL/media-desk/media-statements/2015/labour-minister-oliphant-increases-farmworkers-minimum-wage-by-7-7-percent-in-2015-16/?searchterm=farmworkers.>

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(9):1308-1311.

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.

ANNEXURE: Evaluation of the Efficacy of a Combined Application of Prohexadione-calcium and Gibberellins$_{4+7}$ as Chemical Thinner in Stone Fruit.

Included in this study was the evaluation of a combined application of prohexadione-calcium (Pro-Ca) and Gibberellins$_{4+7}$ (GA_{4+7}), even though they are not regularly used to thin stone fruit at the fruitlet stage. The reason for the evaluating of these two well-known plant growth regulators was a talk Dr. Gottfried Lafer presented at the EUFRIN thinning working group in March 2013 in Lisbon, Portugal. Lafer found promising fruit thinning on peaches, but also severe leaf drop (Unpublished Power Point presentation, 2013). Due to personal communication between Dr. Lafer and Prof. Karen Theron it was decided that these two plant growth regulators will be included in this study.

Annexure A: 'African Rose™'

Materials and methods

Plant material and site description. In 2013/2014, a trial was conducted on the Japanese plum 'African Rose™' in an orchard situated near Wellington on the farm Sandrivier (33°35'58.0" S, 18°55'40.1" E) in the Western Cape, South Africa. The mature 'African Rose™' trees, on Marianna rootstocks, 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 the cross pollinator.

Experimental layout. Two plant growth regulators were evaluated, Pro-Ca (Regalis®; BASF, Midrand 1685, South Africa) and GA_{4+7} (Regulex®; Philagro SA, Somerset West, South Africa). Five treatments were used as summarised in Table 1. A randomised complete block design with eight single tree replications was used. All the foliar applications were made using a motorised knapsack sprayer (STIHL, Pietermaritzburg, South Africa) when the average fruitlet size was 7-10 mm. Each tree was sprayed for 30 seconds, thus applying approximately 1L of solution per tree 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 for all the trials were favourable for at least five days with temperatures above 18 ^{o}C. Dates of chemical application, hand thinning and harvests are summarised in Table 2.

Data collection.

See Paper 1.

Statistical analysis.

See Paper 1.

Results

Table 1. Treatment specifications for trials done with prohexadione-calcium (Pro-Ca) and GA 4+7 on 'African Rose™' plums in the season of 2013/2014.

Treatment
Untreated control
Pro-Ca and GA_{4+7} (15g + 1.5g) at 30 DAFB
Pro-Ca and GA_{4+7} (15g + 1.5g) at 40 DAFB
Pro-Ca and GA_{4+7} (20g + 2.0g) at 30 DAFB
Pro-Ca and GA_{4+7} (20g + 2.0g) at 40 DAFB

Table 2. Summary of the dates of treatment application, follow up hand thinning of fruitlets and harvest for 'African Rose™' in the season of 2013/2014.

Phenological stage	African Rose™
	prohexadione-calcium and GA_{4+7}
Application	11 Sept. 2013 (30 DAFB) and 21 Sept. 2013 (40 DAFB)
Follow up hand thinning of fruitlets	1 Oct. 2013
Harvest	18, 21 Nov. 2013

Table 3. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit set and thinning required in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment*	Average number of fruitlets thinned by hand	Average weight of hand thinned fruitlets (g)	Time to thin ($min{\cdot}tree^{-1}$)
Control	1694 ns	2.3 ns	1207 ns
Low Pro-Ca +GA_{4+7} 30DAFB	1620	2.3	1292
Low Pro-Ca +GA_{4+7} 40DAFB	1759	2.2	1510
High Pro-Ca +GA_{4+7} 30DAFB	1579	2.3	1442
High Pro-Ca +GA_{4+7} 40DAFB	1752	2.2	1325
Significance level	*0.5812*	*0.6178*	*0.3294*
LSD 5%	-	-	-

* Low: Pro-Ca (15 g) and GA $_{4+7}$ (1.5g); High: Pro-Ca (20g) and GA $_{4+7}$ (2.0g)

Table 4. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on yield and yield efficiency in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment*	Total yield per tree (kg)	Estimated yield per hectare (ton)	Yield efficiency first harvest ($kg{\cdot}cm^{-2}$)	Yield efficiency second harvest ($kg{\cdot}cm^{-2}$)	Total yield efficiency ($kg{\cdot}cm^{-2}$)
Control	13.9 ns	39.7	0.10 ns	0.23 ns	0.32 ns
Low Pro-Ca +GA_{4+7} 30DAFB	13.7	39.1	0.08	0.19	0.27
Low Pro-Ca +GA_{4+7} 40DAFB	13.2	37.7	0.08	0.20	0.28
High Pro-Ca +GA_{4+7} 30DAFB	14.5	41.4	0.11	0.26	0.33
High Pro-Ca +GA_{4+7} 40DAFB	12.1	34.6	0.08	0.19	0.26
Significance level	*0.0922*	-	*0.2445*	*0.4528*	*0.1951*
LSD 5%	-	-	-	-	-

* Low: Pro-Ca (15 g) and GA $_{4+7}$ (1.5g); High: Pro-Ca (20g) and GA $_{4+7}$ (2.0g)

Table 5. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on harvest distribution and fruit weight in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment*	Percentage of fruit picked at first harvest	Percentage of fruit picked at second harvest	Average fruit weight (g)
Control	30.5 ns	69.6 ns	50.7 ns
Low Pro-Ca +GA_{4+7} 30DAFB	30.4	69.6	51.4
Low Pro-Ca +GA_{4+7} 40DAFB	28.6	71.5	51.7
High Pro-Ca +GA_{4+7} 30DAFB	32.8	67.2	51.5
High Pro-Ca +GA_{4+7} 40DAFB	28.1	71.9	52.0
Significance level	*0.7507*	*0.7507*	*0.9767*
LSD 5%	-	-	-

* Low: Pro-Ca (15 g) and GA $_{4+7}$ (1.5g); High: Pro-Ca (20g) and GA $_{4+7}$ (2.0g)

Table 6. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit size and shape at first harvest in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment*	Average fruit weight at first harvest (g)		Average fruit diameter at first harvest (mm)		Average fruit length at first harvest (mm)		Average fruit length to diameter ratio at first harvest	
Control	49.2	ns	42.0	ns	39.4	b	0.94	b
Low Pro-Ca +GA_{4+7} 30DAFB	49.9		42.1		39.3	b	0.93	b
Low Pro-Ca +GA_{4+7} 40DAFB	50.6		42.4		40.9	a	0.96	a
High Pro-Ca +GA_{4+7} 30DAFB	49.8		42.2		40.8	a	0.97	a
High Pro-Ca +GA_{4+7} 40DAFB	50.8		42.3		41.2	a	0.97	a
Significance level	*0.9371*		*0.9773*		*0.0104*		*0.0001*	
LSD 5%	-		-		*1.29*		*0.02*	

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); High: Pro-Ca (20g) and GA_{4+7} (2.0g)

Table 7. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit size and shape at second harvest in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment*	Average fruit weight at second harvest (g)		Average fruit diameter at second harvest (mm)		Average fruit length at second harvest (mm)		Average fruit length to diameter ratio at second harvest	
Control	52.1	ns	44.2	ns	40.6	ns	0.92	ns
Low Pro-Ca +GA_{4+7} 30DAFB	52.8		44.6		40.9		0.92	
Low Pro-Ca +GA_{4+7} 40DAFB	52.8		44.5		40.9		0.92	
High Pro-Ca +GA_{4+7} 30DAFB	53.2		44.7		41.1		0.92	
High Pro-Ca +GA_{4+7} 40DAFB	53.1		45.0		40.9		0.91	
Significance level	*0.9905*		*0.7841*		*0.9376*		*0.6611*	
LSD 5%	-		-		-		-	

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); High: Pro-Ca (20g) and GA_{4+7} (2.0g)

Table 8. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit firmness in 'African Rose™' plum at Sandrivier, Wellington district, South Africa (2013/2014).

Treatment*	Average fruit firmness at first harvest (kg)		Average fruit firmness at second harvest (kg)	
Control	6.8	ns	6.1	b
Low Pro-Ca +GA_{4+7} 30DAFB	7.1		6.7	a
Low Pro-Ca +GA_{4+7} 40DAFB	7.1		6.7	a
High Pro-Ca +GA_{4+7} 30DAFB	7.0		6.0	b
High Pro-Ca +GA_{4+7} 40DAFB	7.2		6.9	a
Significance level	*0.3058*		*0.0127*	
LSD 5%	-		*0.56*	

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); High: Pro-Ca (20g) and GA_{4+7} (2.0g)

Annexure B: 'Golden Pride' and 'Western Sun'

Materials and methods

Plant material and site description. Trials were conducted on the cling peach cultivars Western Sun and Golden Pride. The 'Western Sun' orchard was near Wolseley in the Western Cape, South Africa, on the farm La Plaisante (33^{o}27'16.8" S, 19^{o}12'33.1" E). The 'Western Sun' trees on Kakamas rootstocks were planted in 2006 at 4.5 m x 2 m and trained to a conventional central leader system characterized by strong lower scaffold branches and a triangular tree shape. The 'Golden Pride' orchard was near Tulbagh in the Western Cape, South Africa, on the farm Fisaasbos (33^{o}11'05.3" S 19^{o}09'07.8"E). The 'Golden Pride' trees on Kakamas rootstocks were planted in 2007 at 5m x 2m and also trained to a conventional "Kers en blaker" central leader system characterized by strong lower scaffold branches and a triangular tree shape.

Experimental layout. Two plant growth regulators were evaluated, Pro-Ca (Regalis®; BASF, Midrand 1685, South Africa) and GA_{4+7} (Regulex®; Philagro SA, Somerset West, South Africa). Four treatments were used as summarised in Table 9. A randomised complete block design with eight single tree replications was used. All the foliar applications were made using a motorised knapsack sprayer (STIHL, Pietermaritzburg, South Africa) when the average fruitlet size was 7-10 mm. Each tree was sprayed for 30 seconds, thus applying approximately 1L of solution per tree under slow drying conditions when the temperature was between 10 and 15 ^{o}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 for all the trials were favourable for at least five days with temperatures above 18 ^{o}C. Dates of chemical application, hand thinning and harvests are summarised in Table 10.

Data collection.

See Paper 2.

Statistical analysis.

See Paper 2.

Results

Table 9. Treatment specifications for trials done with prohexadione-calcium (Pro-Ca) and GA_{4+7} on cultivars Western Sun and Golden Pride cling peaches in the season of 2013/2014.

Treatments
Untreated control
Pro-Ca and GA_{4+7} (15g + 1.5g) at 40 DAFB
Pro-Ca and GA_{4+7} (20g + 2.0g) at 40 DAFB
Pro-Ca and GA_{4+7} (25g + 2.5g) at 40 DAFB

Table 10. Summary of the dates of treatment application, follow up hand thinning of fruitlets and harvest for 'Golden Pride' and 'Western Sun' cling peach in the season of 2013/2014.

Phenological stage	prohexadione-calcium and GA_{4+7}	
	'Golden Pride'	'Western Sun'
Application	22 Sept. 2013 (30 DAFB) and 2 Oct. 2013 (40 DAFB)	22 Sept. 2013 (30 DAFB) and 2 Oct. 2013 (40 DAFB)
Follow up hand thinning of fruitlets	9 Oct. 2013	8 Oct. 2013
Harvest	23, 29 Jan. 2014 and 04, 10 Feb. 2014	14, 20, 27 Jan. 2014

Table 11. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit set and thinning required in 'Western Sun' peach at La Plaisante, Wolseley, South Africa (2013/2014).

Treatment*	Average fruit set on 8 1-yr-old shoots	Average number of fruitlets thinned by hand	Average weight of hand thinned fruitlets (g)
Control	56.2 ns	398 ns	5.5 ns
Low Pro-Ca +GA_{4+7} 40DAFB	60.3	442	5.4
Mid. Pro-Ca +GA_{4+7} 40DAFB	57.8	399	5.2
High Pro-Ca +GA_{4+7} 40DAFB	61.9	369	6.0
Significance level	*0.4910*	*0.5859*	*0.1970*
LSD 5%	-	-	-

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); Mid.: Pro-Ca (20 g) and GA_{4+7} (2.0g); High: Pro-Ca (25 g) and GA_{4+7} (2.5g)

Table 12. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on yield and yield efficiency in 'Western Sun' peach at La Plaisante, Wolseley, South Africa (2013/2014).

Treatment*	Total yield per tree (kg)	Estimated yield per hectare (ton)	Yield efficiency first harvest ($kg \cdot cm^{-2}$)
Control	45.4 ns	50.4	0.08 ns
Low Pro-Ca +GA_{4+7} 40DAFB	49.7	55.2	0.08
Mid. Pro-Ca +GA_{4+7} 40DAFB	43.2	48.0	0.07
High Pro-Ca +GA_{4+7} 40DAFB	42.8	47.5	0.06
Significance level	*0.3593*	-	*0.2922*
LSD 5%	-	-	-

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); Mid.: Pro-Ca (20 g) and GA_{4+7} (2.0g); High: Pro-Ca (25 g) and GA_{4+7} (2.5g)

Table 13. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on yield efficiency in 'Western Sun' peach at La Plaisante, Wolseley, South Africa (2013/2014).

Treatment*	Yield efficiency second harvest ($kg \cdot cm^{-2}$)	Yield efficiency third harvest ($kg \cdot cm^{-2}$)	Total yield efficiency ($kg \cdot cm^{-2}$)
Control	0.15 ns	0.25 ns	0.47 ns
Low Pro-Ca +GA_{4+7} 40DAFB	0.14	0.25	0.47
Mid. Pro-Ca +GA_{4+7} 40DAFB	0.12	0.23	0.42
High Pro-Ca +GA_{4+7} 40DAFB	0.13	0.19	0.38
Significance level	*0.2008*	*0.4849*	*0.2922*
LSD 5%	-	-	-

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); Mid.: Pro-Ca (20 g) and GA_{4+7} (2.0g); High: Pro-Ca (25 g) and GA_{4+7} (2.5g)

Table 14. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on harvest distribution and fruit weight in 'Western Sun' peach at La Plaisante, Wolseley, South Africa (2013/2014).

Treatment*	Percentage of fruit picked at first harvest**	Percentage of fruit picked at second harvest	Percentage of fruit picked at third harvest	Average fruit weight (g)
Control	16.7 ns	32.1 ns	51.3 ns	140.6 ns
Low Pro-Ca +GA_{4+7} 40DAFB	16.7	31.7	51.7	136.8
Mid. Pro-Ca +GA_{4+7} 40DAFB	16.7	29.3	54.1	139.2
High Pro-Ca +GA_{4+7} 40DAFB	16.7	33.3	50.0	134.4
Significance level	-	*0.6881*	*0.6881*	*0.6740*
LSD 5%	-	-	-	-

* Low: Pro-Ca (15 g) and GA $_{4+7}$ (1.5g); Mid.: Pro-Ca (20 g) and GA $_{4+7}$ (2.0g); High: Pro-Ca (25 g) and GA $_{4+7}$ (2.5g)

** First harvest was picked by grower and these means are averages for the orchard where approximately 20% of fruit were picked at first harvest

Table 15. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit size and shape at second harvest in 'Western Sun' peach at La Plaisante, Wolseley, South Africa (2013/2014).

Treatment*	Average fruit weight at second harvest (g)	Average fruit diameter at second harvest (mm)	Average fruit length at second harvest (mm)	Average fruit length to diameter ratio at second harvest
Control	141.2 ns	64.5 ns	57.5 a	0.89 a
Low Pro-Ca +GA_{4+7} 40DAFB	133.7	63.2	55.5 b	0.88 ab
Mid. Pro-Ca +GA_{4+7} 40DAFB	135.7	63.6	55.4 b	0.87 b
High Pro-Ca +GA_{4+7} 40DAFB	128.9	62.7	55.0 b	0.88 ab
Significance level	*0.2788*	*0.3040*	*0.0494*	*0.1578*
LSD 5%	-	-	*1.83*	*0.02*

* Low: Pro-Ca (15 g) and GA $_{4+7}$ (1.5g); Mid.: Pro-Ca (20 g) and GA $_{4+7}$ (2.0g); High: Pro-Ca (25 g) and GA $_{4+7}$ (2.5g)

Table 16. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit size and shape at third harvest in 'Western Sun' peach at La Plaisante, Wolseley, South Africa (2013/2014).

Treatment*	Average fruit weight at third harvest (g)	Average fruit diameter at third harvest (mm)	Average fruit length at third harvest (mm)	Average fruit length to diameter ratio at third harvest
Control	140.0 ns	65.0 ns	57.6 ns	0.89 a
Low Pro-Ca +GA_{4+7} 40DAFB	140.0	65.2	57.5	0.88 ab
Mid. Pro-Ca +GA_{4+7} 40DAFB	142.7	66.0	57.4	0.87 b
High Pro-Ca +GA_{4+7} 40DAFB	139.8	65.3	56.9	0.87 b
Significance level	*0.9693*	*0.8154*	*0.9099*	*0.0583*
LSD 5%	-	-	-	*0.01*

* Low: Pro-Ca (15 g) and GA $_{4+7}$ (1.5g); Mid.: Pro-Ca (20 g) and GA $_{4+7}$ (2.0g); High: Pro-Ca (25 g) and GA $_{4+7}$ (2.5g)

Table 17. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit firmness in 'Western Sun' peach at La Plaisante, Wolseley, South Africa (2013/2014).

Treatment*	Average fruit firmness at second harvest (kg)	Average fruit firmness at third harvest (kg)
Control	7.2 ns	6.3 ns
Low Pro-Ca +GA_{4+7} 40DAFB	6.9	6.4
Mid. Pro-Ca +GA_{4+7} 40DAFB	6.8	6.3
High Pro-Ca +GA_{4+7} 40DAFB	6.8	6.6
Significance level	*0.6654*	*0.7741*
LSD 5%	-	-

* Low: Pro-Ca (15 g) and GA $_{4+7}$ (1.5g); Mid.: Pro-Ca (20 g) and GA $_{4+7}$ (2.0g); High: Pro-Ca (25 g) and GA $_{4+7}$ (2.5g)

Table 18. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit set and thinning required in 'Golden Pride' peach at Fisaasbos, Tulbagh, South Africa (2013/2014).

Treatment*	Average fruit set on 8 1-yr-old shoots	Average number of fruitlets thinned by hand	Average weight of hand thinned fruitlets (g)
Control	63.5 ns	357 ns	6.7 a
Low Pro-Ca +GA_{4+7} 40DAFB	56.4	352	5.5 b
Mid. Pro-Ca +GA_{4+7} 40DAFB	58.1	362	5.3 b
High Pro-Ca +GA_{4+7} 40DAFB	57.3	373	5.2 b
Significance level	*0.3604*	*0.1800*	*0.0001*
LSD 5%	-	-	*0.55*

* Low: Pro-Ca (15 g) and GA $_{4+7}$ (1.5g); Mid.: Pro-Ca (20 g) and GA $_{4+7}$ (2.0g); High: Pro-Ca (25 g) and GA $_{4+7}$ (2.5g)

Table 19. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on yield and yield efficiency in 'Golden Pride' peach at Fisaasbos, Tulbagh, South Africa (2013/2014).

Treatment*	Total yield per tree (kg)	Estimated yield per hectare (ton)	Yield efficiency first harvest (kg.cm-2)	Yield efficiency second harvest (kg.cm-2)
Control	55.7 a	55.7	0.11 a	0.30 a
Low Pro-Ca +GA_{4+7} 40DAFB	43.2 b	43.2	0.08 ab	0.25 a
Mid. Pro-Ca +GA_{4+7} 40DAFB	43.9 b	43.9	0.06 b	0.21 a
High Pro-Ca +GA_{4+7} 40DAFB	24.6 c	24.6	0.13 a	0.05 b
Significance level	*0.0002*	-	*0.0317*	*0.0006*
LSD 5%	*11.44*	-	*0.05*	*0.11*

* Low: Pro-Ca (15 g) and GA $_{4+7}$ (1.5g); Mid.: Pro-Ca (20 g) and GA $_{4+7}$ (2.0g); High: Pro-Ca (25 g) and GA $_{4+7}$ (2.5g)

Table 20. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on yield efficiency in 'Golden Pride' peach at Fisaasbos, Tulbagh, South Africa (2013/2014).

Treatment*	Yield efficiency third harvest (kg.cm-2)		Yield efficiency fourth harvest (kg.cm-2)		Total yield efficiency (kg.cm-2)	
Control	0.33	ns	0.10	ns	0.84	a
Low Pro-Ca +GA_{4+7} 40DAFB	0.26		0.05		0.64	b
Mid. Pro-Ca +GA_{4+7} 40DAFB	0.21		0.07		0.54	bc
High Pro-Ca +GA_{4+7} 40DAFB	0.17		0.03		0.37	c
Significance level	*0.0603*		*0.0692*		*0.0002*	
LSD 5%	-		-		*0.18*	

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); Mid.: Pro-Ca (20 g) and GA_{4+7} (2.0g); High: Pro-Ca (25 g) and GA_{4+7} (2.5g)

Table 21. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on harvest distribution and fruit weight in 'Golden Pride' peach at Fisaasbos, Tulbagh, South Africa (2013/2014).

Treatment*	Percentage of fruit picked at first harvest		Percentage of fruit picked at second harvest		Percentage of fruit picked at third harvest		Percentage of fruit picked at fourth harvest		Average weight of fruit (g)	
Control	12.2	b	35.3	a	39.1	ns	13.5	ns	139.6	ns
Low Pro-Ca +GA_{4+7} 40DAFB	11.0	b	38.8	a	42.9		7.4		138.5	
Mid. Pro-Ca +GA_{4+7} 40DAFB	9.1	b	35.8	a	39.2		15.9		150.6	
High Pro-Ca +GA_{4+7} 40DAFB	33.9	a	12.7	b	46.8		6.7		146.5	
Significance level	*0.0001*		*0.0009*		*0.5378*		*0.1762*		*0.2065*	
LSD 5%	*8.80*		*12.50*		-		-		-	

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); Mid.: Pro-Ca (20 g) and GA_{4+7} (2.0g); High: Pro-Ca (25 g) and GA_{4+7} (2.5g)

Table 22. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit size and shape at first harvest in 'Golden Pride' peach at Fisaasbos, Tulbagh, South Africa (2013/2014).

Treatment*	Average fruit weight at first harvest (g)		Average fruit diameter at first harvest (mm)		Average fruit height at first harvest (mm)		Average fruit length to diameter ratio at first harvest	
Control	101.9	ns	66.0	ab	59.1	ns	0.90	ns
Low Pro-Ca +GA_{4+7} 40DAFB	112.1		65.8	b	58.5		0.89	
Mid. Pro-Ca +GA_{4+7} 40DAFB	89.9		68.1	ab	60.5		0.89	
High Pro-Ca +GA_{4+7} 40DAFB	152.7		68.6	a	60.6		0.88	
Significance level	*0.3021*		*0.0946*		*0.2369*		*0.5370*	
LSD 5%	-		*2.64*		-		-	

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); Mid.: Pro-Ca (20 g) and GA_{4+7} (2.0g); High: Pro-Ca (25 g) and GA_{4+7} (2.5g)

Table 23. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit size and shape at second harvest in 'Golden Pride' peach at Fisaasbos, Tulbagh, South Africa (2013/2014).

Treatment*	Average fruit weight at second harvest (g)	Average fruit diameter at second harvest (mm)	Average fruit height at second harvest (mm)	Average fruit length to diameter ratio at second harvest
Control	132.7 ns	67.0 ns	59.9 ns	0.89 ns
Low Pro-Ca +GA_{4+7} 40DAFB	137.8	67.3	60.5	0.90
Mid. Pro-Ca +GA_{4+7} 40DAFB	130.9	69.8	62.2	0.89
High Pro-Ca +GA_{4+7} 40DAFB	-	68.9	61.4	0.89
Significance level	-	*0.0818*	*0.0987*	*0.6801*
LSD 5%	-	-	-	-

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); Mid.: Pro-Ca (20 g) and GA_{4+7} (2.0g); High: Pro-Ca (25 g) and GA_{4+7} (2.5g)

Table 24. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit size and shape at third harvest in 'Golden Pride' peach at Fisaasbos, Tulbagh, South Africa (2013/2014).

Treatment*	Average fruit weight at third harvest (g)	Average fruit diameter at third harvest (mm)	Average fruit height at third harvest (mm)	Average fruit length to diameter ratio at third harvest
Control	136.0 ns	67.3 ab	60.4 a	0.90 ns
Low Pro-Ca +GA_{4+7} 40DAFB	131.7	64.9 c	58.5 b	0.90
Mid. Pro-Ca +GA_{4+7} 40DAFB	138.0	68.1 a	61.5 a	0.90
High Pro-Ca +GA_{4+7} 40DAFB	128.4	65.1 bc	58.4 b	0.90
Significance level	*0.5372*	*0.0143*	*0.0017*	*0.8215*
LSD 5%	-	*2.22*	*1.67*	-

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); Mid.: Pro-Ca (20 g) and GA_{4+7} (2.0g); High: Pro-Ca (25 g) and GA_{4+7} (2.5g)

Table 25. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit firmness in 'Golden Pride' peach at Fisaasbos, Tulbagh, South Africa (2013/2014).

Treatment*	Average fruit firmness at first harvest (kg)	Average fruit firmness at second harvest (kg)	Average fruit firmness at third harvest (kg)
Control	6.6 b	6.2 c	6.0 b
Low Pro-Ca +GA_{4+7} 40DAFB	6.9 b	6.9 b	6.9 a
Mid. Pro-Ca +GA_{4+7} 40DAFB	7.1 ab	7.2 b	7.3 a
High Pro-Ca +GA_{4+7} 40DAFB	7.7 a	7.6 a	7.3 a
Significance level	*0.0245*	*0.0001*	*0.0065*
LSD 5%	*0.71*	*0.41*	*0.78*

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); Mid.: Pro-Ca (20 g) and GA_{4+7} (2.0g); High: Pro-Ca (25 g) and GA_{4+7} (2.5g)

Annexure C: 'Luciana'

Materials and methods

Plant material and site description for the 20134/2014 season. A trial was conducted on the nectarine 'Luciana' in an orchard situated in the Warm Bokkeveld on the farm Lushof (33°18'12.2"S 19°22'18.1"E) near Prince Alfred's Hamlet in the Western Cape, South Africa. Trees on on Kakamas rootstocks were planted in 2009 at 4 m x 2 m and trained to a Slender Spindle system.

Experimental layout of 2013/2014 season. Two plant growth regulators were evaluated, Pro-Ca (Regalis®; BASF, Midrand 1685, South Africa) and GA_{4+7} (Regulex®; Philagro SA, Somerset West, South Africa). Seven treatments were used as summarised in Table 26. A randomised complete block design with eight single tree replications was used. All the foliar applications were made using a motorised knapsack sprayer (STIHL, Pietermaritzburg, South Africa) when the average fruitlet size was 6-10 mm. Each tree was sprayed for 30 seconds, thus applying approximately 1L of solution per tree 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 for all the trials were favourable for at least five days with temperatures above 18 °C. Dates of chemical application, hand thinning and harvests are summarised in Table 27.

Data collection.

See Paper 3.

Statistical analysis.

See Paper 3.

Results

Table 26. Treatment specifications for trials done with prohexadione-calcium (Pro-Ca) and GA_{4+7} on 'Luciana' nectarines in the season of 2013/2014

Treatments
Untreated control
Pro-Ca and GA_{4+7} (15g + 1.5g) at 30 DAFB
Pro-Ca and GA_{4+7} (15g + 1.5g) at 40 DAFB
Pro-Ca and GA_{4+7} (20g + 2.0g) at 30 DAFB
Pro-Ca and GA_{4+7} (20g + 2.0g) at 40 DAFB
Pro-Ca and GA_{4+7} (25g + 2.5g) at 30 DAFB
Pro-Ca and GA_{4+7} (25g + 2.5g) at 40 DAFB

Table 27. Summary of the dates of treatment application, follow up hand thinning of fruitlets and harvest for 'Luciana' nectarines in the season of 2013/2014.

Phenological stage	prohexadione-calcium and GA_{4+7}
	Luciana
Application	30 Sept. 2013 (30 DAFB) and 8 Oct. 2013 (40 DAFB)
Follow up hand thinning of fruitlets	N/a
Harvest	23, 26 and 31 Dec. 2013

Table 28. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit set and thinning required in 'Luciana' nectarine at Lushof, Prince Alfred's Hamlet, South Africa (2013/2014).

Treatment*	Average fruit set on 8 1-yr-old shoots per tree	
Control	91.7	b
Low Pro-Ca +GA_{4+7} 30DAFB	95.9	a
Low Pro-Ca +GA_{4+7} 40DAFB	93.2	ab
Mid. Pro-Ca +GA_{4+7} 30DAFB	95.4	a
Mid. Pro-Ca +GA_{4+7} 40DAFB	93.7	ab
High Pro-Ca +GA_{4+7} 30DAFB	95.9	a
High Pro-Ca +GA_{4+7} 40DAFB	95.3	a
Significance level	*0.0263*	
LSD 5%	*2.75*	

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); Mid.: Pro-Ca (20 g) and GA_{4+7} (2.0g); High: Pro-Ca (25 g) and GA_{4+7} (2.5g)

Table 29. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on yield and yield efficiency in 'Luciana' nectarine at Lushof, Prince Alfred's Hamlet South Africa (2013/2014).

Treatment*	Total yield per tree (kg)	Estimated yield per hectare (ton)	Yield efficiency first harvest (kg.cm-2)	Yield efficiency second harvest (kg.cm-2)	Yield efficiency third harvest (kg.cm-2)	Total yield efficiency (kg.cm-2)
Control	30.2 ns	37.8	0.21 ns	0.17 ns	0.28 ns	0.65 ns
Low Pro-Ca +GA_{4+7} 30DAFB	28.3	35.3	0.25	0.12	0.20	0.57
Low Pro-Ca +GA_{4+7} 40DAFB	31.7	39.6	0.27	0.16	0.27	0.70
Mid. Pro-Ca +GA_{4+7} 30DAFB	29.6	37.0	0.20	0.20	0.35	0.76
Mid. Pro-Ca +GA_{4+7} 40DAFB	31.3	39.1	0.23	0.14	0.29	0.66
High Pro-Ca +GA_{4+7} 30DAFB	27.6	34.5	0.20	0.21	0.27	0.67
High Pro-Ca +GA_{4+7} 40DAFB	29.1	36.3	0.22	0.19	0.27	0.69
Significance level	*0.6772*	-	*0.4820*	*0.0545*	*0.6322*	*0.2330*
LSD 5%	-	-	-	-	-	-

* Low: Pro-Ca (15 g) and GA $_{4+7}$ (1.5g); Mid.: Pro-Ca (20 g) and GA $_{4+7}$ (2.0g); High: Pro-Ca (25 g) and GA $_{4+7}$ (2.5g)

Table 30. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on harvest distribution and fruit weight in 'Luciana' nectarine at Lushof, Prince Alfred's Hamlet, South Africa (2013/2014).

Treatment*	Percentage of fruit picked at first harvest	Percentage of fruit picked at second harvest	Percentage of fruit picked at third harvest	Average weight of fruit (g)
Control	33.8 ns	26.4 ns	39.8 ns	146.8 ns
Low Pro-Ca +GA_{4+7} 30DAFB	45.3	20.5	34.2	141.1
Low Pro-Ca +GA_{4+7} 40DAFB	38.6	23.9	37.5	138.9
Mid. Pro-Ca +GA_{4+7} 30DAFB	28.0	26.8	45.2	140.2
Mid. Pro-Ca +GA_{4+7} 40DAFB	36.3	20.9	42.9	144.3
High Pro-Ca +GA_{4+7} 30DAFB	27.8	33.2	39.1	134.9
High Pro-Ca +GA_{4+7} 40DAFB	37.3	27.3	35.4	138.1
Significance level	*0.1621*	*0.2590*	*0.8221*	*0.1495*
LSD 5%	-	-	-	-

* Low: Pro-Ca (15 g) and GA $_{4+7}$ (1.5g); Mid.: Pro-Ca (20 g) and GA $_{4+7}$ (2.0g); High: Pro-Ca (25 g) and GA $_{4+7}$ (2.5g)

Table 31. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit size and shape at first harvest in 'Luciana' nectarine at Lushof, Prince Alfred's Hamlet, South Africa (2013/2014).

Treatment*	Average fruit weight at first harvest (g)	Average fruit diameter at first harvest (mm)	Average fruit length at first harvest (mm)	Average fruit length to diameter ratio at first harvest
Control	155.4 ns	65.0 ns	62.7 ns	0.97 c
Low Pro-Ca +GA_{4+7} 30DAFB	152.4	64.7	63.4	0.98 abc
Low Pro-Ca +GA_{4+7} 40DAFB	147.5	64.1	62.7	0.98 abc
Mid. Pro-Ca +GA_{4+7} 30DAFB	152.7	64.8	62.8	0.97 bc
Mid. Pro-Ca +GA_{4+7} 40DAFB	153.5	64.4	63.5	0.99 ab
High Pro-Ca +GA_{4+7} 30DAFB	141.4	62.9	62.0	0.99 a
High Pro-Ca +GA_{4+7} 40DAFB	144.4	63.1	62.2	0.99 a
Significance level	*0.1951*	*0.1058*	*0.4638*	*0.0415*
LSD 5%	-	-	-	*0.02*

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); Mid.: Pro-Ca (20 g) and GA_{4+7} (2.0g); High: Pro-Ca (25 g) and GA_{4+7} (2.5g)

Table 32. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit size and shape at second harvest in 'Luciana' nectarine at Lushof, Prince Alfred's Hamlet, South Africa (2013/2014).

Treatment*	Average fruit weight at second harvest (g)	Average fruit diameter at second harvest (mm)	Average fruit length at second harvest (mm)	Average fruit length to diameter ratio at second harvest
Control	138.2 ns	63.4 a	59.9 ns	0.94 ns
Low Pro-Ca +GA_{4+7} 30DAFB	129.8	61.9 bc	58.3	0.94
Low Pro-Ca +GA_{4+7} 40DAFB	130.4	61.8 bc	58.6	0.95
Mid. Pro-Ca +GA_{4+7} 30DAFB	127.6	61.1 c	57.2	0.94
Mid. Pro-Ca +GA_{4+7} 40DAFB	135.1	62.7 ab	59.3	0.95
High Pro-Ca +GA_{4+7} 30DAFB	128.4	61.7 bc	57.9	0.94
High Pro-Ca +GA_{4+7} 40DAFB	131.8	62.2 abc	58.6	0.94
Significance level	*0.1244*	*0.0233*	*0.05*	*0.9736*
LSD 5%	-	*1.25*	-	-

* Low: Pro-Ca (15 g) and GA_{4+7} (1.5g); Mid.: Pro-Ca (20 g) and GA_{4+7} (2.0g); High: Pro-Ca (25 g) and GA_{4+7} (2.5g)

Table 33. Effect of prohexadione-calcium (Pro-Ca) and GA_{4+7} on fruit firmness in 'Luciana' nectarine, Lushof, Prince Alfred's Hamlet, South Africa (2013/2014).

Treatment*	Average fruit firmness at first harvest (kg)		Average fruit firmness at second harvest (kg)	
Control	12.6	ns	11.6	a
Low Pro-Ca +GA_{4+7} 30DAFB	12.4		11.6	a
Low Pro-Ca +GA_{4+7} 40DAFB	12.4		11.0	abc
Mid. Pro-Ca +GA_{4+7} 30DAFB	12.2		10.6	bc
Mid. Pro-Ca +GA_{4+7} 40DAFB	12.1		11.0	abc
High Pro-Ca +GA_{4+7} 30DAFB	12.1		10.4	c
High Pro-Ca +GA_{4+7} 40DAFB	11.9		11.3	ab
Significance level	*0.5094*		*0.0091*	
LSD 5%	-		*0.73*	

* Low: Pro-Ca (15 g) and GA $_{4+7}$ (1.5g); Mid.: Pro-Ca (20 g) and GA $_{4+7}$ (2.0g); High: Pro-Ca (25 g) and GA $_{4+7}$ (2.5g)

Annexure D: 'Alpine'

Materials and methods

See Paper 3.

Data collection.

See Paper 3.

Statistical analysis.

See Paper 3.

Results

Table 1. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit set and thinning required in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South Africa (2014/2015).

Treatment	Average fruit set on 5 1-yr-old shoots	Average number of fruitlets thinned by hand	Average weight of hand thinned fruitlets (g)
Control	71.0 abc	1165 b	7.9 bc
Darwin at full bloom	68.4 bc	454 cd	9.5 a
Flower thinning	76.7 a	609 c	9.2 a
6-BA 100	72.0 abc	1070 b	7.9 b
ACC 200	66.1 c	1159 b	7.8 bcd
ACC 400	65.8 c	1394 a	7.2 cd
ACC 600	71.3 abc	1235 ab	7.1 d
6-BA + ACC*	67.2 c	1067 b	7.3 bcd
Darwin + ACC 400	66.2 c	394 cd	9.6 a
Darwin + ACC 600	74.7 ab	358 d	9.5 a
Significance level	*0.0261*	*<0.0001*	*<0.0001*
LSD 5%	*7.17*	*222.77*	*0.75*
ACC vs. ACC + Darwin	*0.4590*	*<0.0001*	*<0.0001*
ACC Linear	*0.1541*	*0.5009*	*0.0601*
ACC Quadratic	*0.3598*	*0.0456*	*0.4174*
Control vs. Rest	*0.6573*	*0.0005*	*0.0954*

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 2. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on yield and yield efficiency in 'Alpine' nectarine, at Swartdam, Riebeek Kasteel, South Africa (2014/2015).

Treatment	Total yield per tree (kg)		Estimated yield per hectare (ton)	Yield efficiency of first harvest ($kg \cdot cm^{-2}$)		Yield efficiency of second harvest ($kg \cdot cm^{-2}$)	
Control	34.7	ab	43.4	0.01	abcd	0.02	b
Darwin at full bloom	29.5	bcd	36.8	0.01	a	0.07	a
Flower thinning	35.3	ab	44.1	0.01	ab	0.05	a
6-BA 100	32.2	bc	40.2	0.01	abcd	0.02	b
ACC 200	30.8	bcd	38.5	0.01	abcd	0.03	b
ACC 400	40.0	a	50.0	0.00	d	0.02	b
ACC 600	32.1	bc	40.2	0.00	d	0.02	b
6-BA + ACC*	30.6	bcd	38.3	0.01	abcd	0.02	b
Darwin + ACC 400	27.1	cd	33.9	0.01	ab	0.07	a
Darwin + ACC 600	25.5	d	31.9	0.01	abc	0.06	a
Significance level	*0.0010*		-	*0.0416*		*<0.0001*	
LSD 5%	*6.28*		-	*0.01*		*0.02*	
ACC vs. ACC + Darwin	*<0.0001*		-	*0.0021*		*<0.0001*	
ACC Linear	*0.6628*		-	*0.1706*		*0.1140*	
ACC Quadratic	*0.0025*		-	*0.1924*		*0.9663*	
Control vs. Rest	*0.1714*		-	*0.9803*		*0.0026*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$)

Table 3. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on yield efficiency in 'Alpine' nectarine, at Swartdam, Riebeek Kasteel, South Africa (2014/2015).

Treatment	Yield efficiency third harvest ($kg{\cdot}cm^{-2}$)		Yield efficiency fourth harvest ($kg{\cdot}cm^{-2}$)		Yield efficiency fifth harvest ($kg.cm^{-2}$)		Yield efficiency sixth harvest ($kg.cm^{-2}$)	
Control	0.03	ns	0.05	d	0.08	a	0.07	abc
Darwin at full bloom	0.04		0.09	ab	0.05	bc	0.04	d
Flower thinning	0.04		0.10	a	0.08	a	0.07	abc
6-BA 100	0.02		0.07	bcd	0.07	ab	0.06	abc
ACC 200	0.04		0.09	abc	0.05	bc	0.06	bcd
ACC 400	0.02		0.08	abcd	0.07	ab	0.08	ab
ACC 600	0.03		0.07	cd	0.05	bc	0.08	a
6-BA + ACC*	0.02		0.09	abc	0.05	bc	0.07	abc
Darwin + ACC 400	0.03		0.08	abcd	0.05	bc	0.05	cd
Darwin + ACC 600	0.03		0.08	abc	0.04	c	0.06	abcd
Significance level	*0.0997*		*0.0435*		*0.0122*		*0.0112*	
LSD 5%	-		*0.03*		*0.02*		*0.02*	
ACC vs. ACC + Darwin	*0.3880*		*0.5337*		*0.0541*		*0.0058*	
ACC Linear	*0.2416*		*0.1761*		*0.9722*		*0.0391*	
ACC Quadratic	*0.2522*		*0.8518*		*0.0570*		*0.3173*	
Control vs. Rest	*0.9628*		*0.0041*		*0.0200*		*0.5573*	

* 6-BA (100 $\mu l{\cdot}L^{-1}$) + ACC (600 $\mu l{\cdot}L^{-1}$)

Table 4. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ yield efficiency in 'Alpine' at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Yield efficiency seventh harvest ($kg \cdot cm^{-2}$)		Yield efficiency eighth harvest ($kg \cdot cm^{-2}$)		Total yield efficiency ($kg \cdot cm^{-2}$)	
Control	0.05	ab	0.15	ab	0.46	abc
Darwin at full bloom	0.03	cde	0.07	cd	0.40	cde
Flower thinning	0.05	abc	0.10	bcd	0.50	ab
6-BA 100	0.05	a	0.15	ab	0.45	abcd
ACC 200	0.04	abcd	0.13	abcd	0.44	bcde
ACC 400	0.06	a	0.20	a	0.53	a
ACC 600	0.06	a	0.14	ab	0.45	bcd
6-BA + ACC*	0.04	bcde	0.14	abc	0.44	bcd
Darwin + ACC 400	0.02	e	0.06	d	0.37	de
Darwin + ACC 600	0.03	de	0.06	d	0.36	e
Significance level	*<0.0001*		*0.0031*		*0.0019*	
LSD 5%	*0.02*		*0.08*		*0.08*	
ACC vs. ACC + Darwin	*<0.0001*		*<0.0001*		*<0.0001*	
ACC Linear	*0.0833*		*0.7872*		*0.8889*	
ACC Quadratic	*0.5197*		*0.0711*		*0.0193*	
Control vs. Rest	*0.2842*		*0.2248*		*0.5158*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$)

Table 5. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on harvest distribution in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, 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		Percentage of fruit picked at fourth harvest	
Control	1.7	bcd	5.1	c	6.6	bcde	12.1	d
Darwin at full bloom	3.7	a	17.3	a	10.8	a	23.7	a
Flower thinning	2.2	abc	11.7	b	8.1	abcd	20.1	abc
6-BA 100	1.3	bcd	5.9	c	5.0	de	17.3	abcd
ACC 200	2.0	abcd	7.3	c	8.7	abc	20.8	abc
ACC 400	0.1	d	5.1	c	4.1	e	16.8	bcd
ACC 600	0.5	cd	4.3	c	5.5	bcde	15.6	cd
6-BA + ACC*	1.6	bcd	5.6	c	5.2	cde	19.6	abc
Darwin + ACC 400	3.2	ab	18.9	a	9.0	ab	22.8	ab
Darwin + ACC 600	3.1	ab	16.6	a	7.8	abcd	23.1	ab
Significance level	*0.0116*		*<0.0001*		*0.0065*		*0.0109*	
LSD 5%	*2.038*		*4.2545*		*3.5602*		*6.4974*	
ACC vs. ACC + Darwin	*0.0002*		*<0.0001*		*0.0061*		*0.0046*	
ACC Linear	*0.1473*		*0.1571*		*0.0756*		*0.1159*	
ACC Quadratic	*0.2301*		*0.7120*		*0.0584*		*0.6439*	
Control vs. Rest	*0.7166*		*0.0018*		*0.7106*		*0.0018*	

* 6-BA (100 μl·L^{-1}) + ACC (600 μl·L^{-1})

Table 6. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on harvest distribution and fruit weight in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Percentage of fruit picked at fifth harvest	Percentage of fruit picked at sixth harvest	Percentage of fruit picked at seventh harvest	Percentage of fruit picked at eighth harvest	Average weight of fruit (g)
Control	17.8 ns	15.1 ab	10.1 abc	31.4 a	119.7 cd
Darwin at full bloom	12.8	9.0 c	7.5 cde	15.1 c	129.4 a
Flower thinning	15.6	14.6 ab	9.1 bcd	18.6 bc	126.2 ab
6-BA 100	14.9	14.2 abc	11.3 ab	30.1 a	122.3 bc
ACC 200	12.0	12.2 bc	9.1 bcd	27.9 ab	118.3 cd
ACC 400	14.2	15.9 ab	10.4 abc	33.3 a	118.1 cd
ACC 600	12.3	19.2 a	12.6 a	30.2 a	116.4 d
6-BA + ACC*	12.8	17.0 ab	7.9 cde	30.3 a	118.5 cd
Darwin + ACC 400	13.4	12.9 bc	6.0 e	14.0 c	130.1 a
Darwin + ACC 600	11.4	16.0 ab	6.8 de	15.3 c	130.9 a
Significance level	*0.3681*	*0.0316*	*0.0010*	*<0.0001*	*<0.0001*
LSD 5%	-	*5.33*	*3.12*	*10.48*	*4.94*
ACC vs. ACC + Darwin	*0.6527*	*0.1076*	*<0.0001*	*<0.0001*	*<0.0001*
ACC Linear	*0.9292*	*0.0114*	*0.0292*	*0.6622*	*0.4278*
ACC Quadratic	*0.3601*	*0.9427*	*0.7610*	*0.3595*	*0.7213*
Control vs. Rest	*0.0224*	*0.7985*	*0.3237*	*0.0574*	*0.0495*

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 7. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit size and shape at second harvest in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Average weight of fruit for second harvest (g)		Average fruit diameter at second harvest (mm)		Average fruit length at second harvest (mm)		Average fruit length to diameter ratio at second harvest	
Control	119.5	d	57.7	ns	52.7	ns	0.82	ns
Darwin at full bloom	143.2	ab	65.8		59.7		0.91	
Flower thinning	136.0	abc	64.5		59.0		0.91	
6-BA 100	134.5	abc	64.4		58.5		0.91	
ACC 200	131.4	bcd	63.8		57.0		0.89	
ACC 400	131.3	bcd	64.3		57.1		0.89	
ACC 600	130.6	bcd	63.9		56.6		0.89	
6-BA + ACC*	129.2	cd	63.5		56.9		0.90	
Darwin + ACC 400	145.2	a	66.3		59.9		0.90	
Darwin + ACC 600	143.1	ab	66.0		59.5		0.90	
Significance level	*0.0074*		*0.2088*		*0.2356*		*0.5904*	
LSD 5%	*13.28*		-		-		-	
ACC vs. ACC + Darwin	*0.0066*		*0.3138*		*0.1339*		*0.6048*	
ACC Linear	*0.8993*		*0.9779*		*0.8558*		*0.8323*	
ACC Quadratic	*0.9574*		*0.8647*		*0.8952*		*0.9706*	
Control vs. Rest	*0.0013*		*0.0018*		*0.0062*		*0.0120*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 8. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit size and shape at third harvest in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South Africa (2014/2015).

Treatment	Average weight of fruit for third harvest (g)		Average fruit diameter at third harvest (mm)		Average fruit length at third harvest (mm)		Average fruit length to diameter ratio at third harvest	
Control	114.5	ns	60.9	ns	54.9	ns	0.90	ns
Darwin at full bloom	128.4		63.2		57.1		0.90	
Flower thinning	121.9		62.2		56.0		0.90	
6-BA 100	117.9		61.5		55.2		0.90	
ACC 200	105.2		55.2		49.0		0.80	
ACC 400	104.3		55.0		49.1		0.80	
ACC 600	113.2		60.6		53.8		0.89	
6-BA + ACC*	94.1		49.1		43.9		0.72	
Darwin + ACC 400	113.0		56.7		50.6		0.80	
Darwin + ACC 600	126.9		63.1		56.0		0.89	
Significance level	*0.1051*		*0.2604*		*0.2220*		*0.2827*	
LSD 5%	-		-		-		-	
ACC vs. ACC + Darwin	*0.1770*		*0.6095*		*0.6133*		*0.9964*	
ACC Linear	*0.4940*		*0.3459*		*0.3524*		*0.2882*	
ACC Quadratic	*0.6304*		*0.5680*		*0.6037*		*0.5695*	
Control vs. Rest	*0.9384*		*0.5848*		*0.5088*		*0.3574*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 9. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit size and shape at fourth harvest in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Average weight of fruit for fourth harvest (g)	Average fruit diameter at fourth harvest (mm)	Average fruit length at fourth harvest (mm)	Average fruit length to diameter ratio at fourth harvest
Control	118.2 d	61.5 d	54.6 bc	0.89 cde
Darwin at full bloom	131.3 ab	63.7 ab	57.4 a	0.90 ab
Flower thinning	126.2 bc	62.9 bc	57.0 a	0.91 a
6-BA 100	120.4 cd	61.8 cd	55.2 b	0.89 bc
ACC 200	117.2 d	61.3 d	54.2 bc	0.88 cdef
ACC 400	116.2 d	61.1 d	53.9 c	0.88 def
ACC 600	115.2 d	61.2 d	53.5 c	0.87 f
6-BA + ACC*	117.8 d	61.5 d	54.4 bc	0.88 cdef
Darwin + ACC 400	133.0 a	64.7 a	56.8 a	0.88 ef
Darwin + ACC 600	132.3 ab	64.0 ab	57.0 a	0.89 bcd
Significance level	*0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
LSD 5%	*6.48*	*1.15*	*1.13*	*0.01*
ACC vs. ACC + Darwin	*<0.0001*	*<0.0001*	*<0.0001*	*0.1575*
ACC Linear	*0.5477*	*0.8140*	*0.2263*	*0.0981*
ACC Quadratic	*0.9850*	*0.7679*	*0.8762*	*0.4800*
Control vs. Rest	*0.0393*	*0.0223*	*0.0355*	*0.9734*

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 10. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit size and shape at fifth harvest in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Average weight of fruit for fifth harvest (g)		Average fruit diameter at fifth harvest (mm)		Average fruit length at fifth harvest (mm)		Average fruit length to diameter ratio at fifth harvest	
Control	112.1	bc	63.8	bc	55.6	b	0.87	bcd
Darwin at full bloom	115.6	ab	64.5	ab	56.5	ab	0.88	bc
Flower thinning	119.1	a	65.3	a	56.8	a	0.87	cd
6-BA 100	112.4	bc	64.2	ab	55.4	bc	0.86	d
ACC 200	106.8	c	62.9	cd	54.2	d	0.86	d
ACC 400	106.6	c	62.1	d	54.1	d	0.87	bcd
ACC 600	106.5	c	61.7	d	54.2	d	0.88	b
6-BA + ACC*	107.2	c	61.8	d	54.3	cd	0.88	b
Darwin + ACC 400	116.9	ab	63.4	bc	56.5	ab	0.89	a
Darwin + ACC 600	121.4	a	64.3	ab	56.4	ab	0.88	bc
Significance level	*<0.0001*		*<0.0001*		*<0.0001*		*<0.0001*	
LSD 5%	*6.71*		*1.26*		*1.15*		*0.01*	
ACC vs. ACC + Darwin	*<0.0001*		*<0.0001*		*<0.0001*		*0.0069*	
ACC Linear	*0.9282*		*0.0658*		*0.9231*		*0.0014*	
ACC Quadratic	*0.9992*		*0.7643*		*0.8158*		*0.9053*	
Control vs. Rest	*0.8682*		*0.3736*		*0.6604*		*0.4120*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 11. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit size and shape at sixth in ‘Alpine’ nectarine at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Average weight of fruit for sixth harvest (g)		Average fruit diameter at sixth harvest (mm)		Average fruit length at sixth harvest (mm)		Average fruit length to diameter ratio at sixth harvest	
Control	124.6	cdef	63.3	cd	57.6	c	0.91	bc
Darwin at full bloom	128.9	abc	63.8	bc	58.7	a	0.92	ab
Flower thinning	127.9	bcd	63.8	bc	58.9	a	0.92	a
6-BA 100	125.3	bcde	63.3	cd	57.7	bc	0.91	abc
ACC 200	118.4	f	62.1	e	56.8	cd	0.91	abc
ACC 400	121.5	def	62.6	de	57.1	cd	0.91	abc
ACC 600	118.5	f	62.1	e	56.6	d	0.91	abc
6-BA + ACC*	119.8	ef	62.4	de	56.6	d	0.91	c
Darwin + ACC 400	131.7	ba	64.5	ab	58.6	ab	0.91	c
Darwin + ACC 600	134.5	a	65.0	a	57.5	cd	0.88	d
Significance level	*<0.0001*		*<0.0001*		*<0.0001*		*<0.0001*	
LSD 5%	*6.46*		*1.12*		*0.95*		*0.01*	
ACC vs. ACC + Darwin	*<0.0001*		*<0.0001*		*0.0005*		*0.0010*	
ACC Linear	*0.9792*		*0.8708*		*0.6572*		*0.7305*	
ACC Quadratic	*0.2832*		*0.2879*		*0.3325*		*0.8354*	
Control vs. Rest	*0.8357*		*0.9417*		*0.9278*		*0.9325*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 12. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit size and shape at seventh harvest in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Average weight of fruit for seventh harvest (g)		Average fruit diameter at seventh harvest (mm)		Average fruit length at seventh harvest (mm)		Average fruit length to diameter ratio at seventh harvest	
Control	117.1	ns	59.6	ns	54.4	ns	0.91	ns
Darwin at full bloom	116.2		55.7		50.8		0.82	
Flower thinning	126.1		61.4		56.1		0.92	
6-BA 100	123.2		60.4		55.1		0.91	
ACC 200	107.2		53.9		49.5		0.83	
ACC 400	116.8		59.3		53.7		0.91	
ACC 600	114.2		58.9		53.0		0.90	
6-BA + ACC*	118.7		59.6		53.8		0.90	
Darwin + ACC 400	114.9		55.2		49.8		0.81	
Darwin + ACC 600	127.2		61.2		56.4		0.92	
Significance level	*0.5296*		*0.6243*		*0.5763*		*0.4550*	
LSD 5%	-		-		-		-	
ACC vs. ACC + Darwin	*0.3826*		*0.7656*		*0.9322*		*0.4216*	
ACC Linear	*0.4361*		*0.2367*		*0.3650*		*0.2457*	
ACC Quadratic	*0.4319*		*0.4259*		*0.4530*		*0.4285*	
Control vs. Rest	*0.8665*		*0.6983*		*0.6541*		*0.4767*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 13. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit firmness in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Average fruit firmness at second harvest (kg)		Average fruit firmness at third harvest (kg)		Average fruit firmness at fourth harvest (kg)	
Control	9.0	c	11.1	a	8.1	bc
Darwin at full bloom	11.3	a	10.6	abc	9.0	ab
Flower thinning	11.0	ab	10.9	ab	9.4	a
6-BA 100	10.9	ab	10.4	abcd	8.6	ab
ACC 200	10.4	abc	8.4	cde	7.0	cde
ACC 400	9.7	bc	8.3	de	6.4	e
ACC 600	9.2	c	8.8	bcde	7.1	cde
6-BA + ACC*	10.0	abc	7.5	e	7.0	cde
Darwin + ACC 400	10.7	ab	9.4	abcde	7.8	bcd
Darwin + ACC 600	9.9	abc	9.2	abcde	6.8	de
Significance level	*0.0236*		*0.0149*		*<0.0001*	
LSD 5%	*1.48*		*2.20*		*1.28*	
ACC vs. ACC + Darwin	*0.0911*		*0.3461*		*0.2823*	
ACC Linear	*0.1025*		*0.7543*		*0.8547*	
ACC Quadratic	*0.8236*		*0.7981*		*0.2251*	
Control vs. Rest	*0.0157*		*0.0314*		*0.4054*	

* 6-BA (100 µl·L^{-1}) + ACC (600 µl·L^{-1})

Table 14. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit firmness in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Average fruit firmness at fifth harvest (kg)		Average fruit firmness at sixth harvest (kg)		Average fruit firmness at seventh harvest (kg)	
Control	11.0	ns	10.6	abc	10.0	ns
Darwin at full bloom	11.5		10.9	ab	9.5	
Flower thinning	11.2		11.0	a	10.5	
6-BA 100	11.3		10.3	abc	10.0	
ACC 200	10.9		10.9	ab	7.7	
ACC 400	11.6		10.3	abc	8.8	
ACC 600	10.9		9.1	d	8.4	
6-BA + ACC*	11.3		9.9	cd	8.9	
Darwin + ACC 400	11.8		10.7	abc	8.4	
Darwin + ACC 600	10.9		10.0	bcd	9.5	
Significance level	*0.3321*		*0.0047*		*0.1545*	
LSD 5%	-		*0.96*		-	
ACC vs. ACC + Darwin	*0.9187*		*0.0630*		*0.6247*	
ACC Linear	*0.9023*		*0.0003*		*0.4691*	
ACC Quadratic	*0.0491*		*0.5525*		*0.4234*	
Control vs. Rest	*0.4428*		*0.3866*		*0.1999*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$)

Table 15. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit pit quality out of 15 fruit in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Average percentage fruit with split pit at second harvest		Average percentage of fruit with split pit at third harvest		Average percentage of fruit with split pit at fourth harvest	
Control	0.01	ns	0.04	ns	0.06	a
Darwin at full bloom	0.02		0.04		0.03	abc
Flower thinning	0.01		0.03		0.03	abc
6-BA 100	0.01		0.03		0.05	ab
ACC 200	0.02		0.03		0.01	c
ACC 400	0.01		0.01		0.02	bc
ACC 600	0.02		0.01		0.00	c
6-BA + ACC*	0.03		0.01		0.00	c
Darwin + ACC 400	0.05		0.00		0.00	c
Darwin + ACC 600	0.03		0.01		0.01	c
Significance level	*0.7688*		*0.3922*		*0.0076*	
LSD 5%	-		-		*0.04*	
ACC vs. ACC + Darwin	*0.1563*		*0.3457*		*0.6165*	
ACC Linear	*1.0000*		*1.0000*		*0.4791*	
ACC Quadratic	*0.6980*		*0.6996*		*0.4140*	
Control vs. Rest	*0.5818*		*0.1510*		*0.0029*	

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$)

Table 16. Effect of 6-benzyladenine (6-BA), 1-aminocyclopropane carboxylic acid (ACC) and Darwin 300™ on fruit pit quality out of 15 fruit in 'Alpine' nectarine at Swartdam, Riebeek Kasteel, South-Africa (2014/2015).

Treatment	Average percentage fruit with split pit at fifth harvest	Average percentage of fruit with split pit at sixth harvest	Average percentage of fruit with split pit at seventh harvest
Control	0.01 ns	0.00 ns	0.00 ns
Darwin at full bloom	0.03	0.01	0.00
Flower thinning	0.03	0.00	0.00
6-BA 100	0.03	0.01	0.00
ACC 200	0.01	0.00	0.00
ACC 400	0.01	0.00	0.00
ACC 600	0.00	0.00	0.00
6-BA + ACC*	0.00	0.00	0.00
Darwin + ACC 400	0.01	0.01	0.00
Darwin + ACC 600	0.01	0.00	0.00
Significance level	*0.2349*	*0.2308*	-
LSD 5%	-	-	-
ACC vs. ACC + Darwin	*0.3201*	*0.1020*	-
ACC Linear	*0.6385*	*1.0000*	-
ACC Quadratic	*0.7861*	*1.0000*	-
Control vs. Rest	*0.9441*	*0.4875*	-

* 6-BA (100 $\mu l \cdot L^{-1}$) + ACC (600 $\mu l \cdot L^{-1}$)